

PREOPERATIONAL INVESTIGATIONS OF ZOOBENTHOS IN
SOUTHEASTERN LAKE MICHIGAN NEAR THE COOK
NUCLEAR PLANT

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ABSTRACT

Analysis of data from investigations of benthic macroinvertebrates (continuing since 1970) is extended through 1974 for major taxa (*Pontoporeia affinis*, *Stylodrilus heringianus*, Tubificidae, Naididae, *Pisidium* spp., *Sphaerium nitidum*, *Sphaerium striatinum* and Chironomidae), and through 1973 for species of Chironomidae, Tubificidae and Naididae at depths less than 16 m. Data on entrainment and impingement of zoobenthos, nocturnal drift of zoobenthos, species composition of *Pisidium* in two surveys, and abundance and composition of smaller benthic invertebrates are presented in special sections.

Collections with 0.15-mm and 0.35-mm screens showed that younger stages of many macroinvertebrates and small species of Naididae and Chironomidae are under-represented in regular survey data, particularly at depths less than 16 m. Nocturnal drift appeared to be an important factor in zoobenthic composition at depths less than 16 m. Entrainment studies showed that significant but unpredictable heterogeneities occur in the intake forebay of the Cook Plant, making estimation of the numbers of entrained zoobenthos very imprecise. Many entrained animals appeared to originate on riprap installed near the plant to suppress erosion of the lake bottom, or on the intake structure.

Statistical capacity to detect changes in zoobenthic abundance which may occur as a result of power generation was set at a 5.5-fold increase or decrease in the ratio of abundances at stations near the plant (inner) to abundances at reference stations (outer), at the 0.05 significance level. This is a large proportional change, but somewhat less than the ten-fold increases accepted as a criterion of impact by other investigators of Great Lakes zoobenthos. Limits to the precision with which change could be detected were set by variances of zonal means drawn across several stations in each depth zone. Year-to-year changes were large, but comparable at inner and outer stations. The large, naturally occurring variations in abundances over small areas of lake bottom diminish the ability to detect changes in abundance while the capacity of zoobenthos in near-shore habitats to repopulate disturbed areas reduces the duration of changed abundances following a transient impact.

INTRODUCTION

Investigations of zoobenthos (aquatic bottom-living animals) near the Cook Plant are part of a program designed essentially to provide background data on the ecology of nearshore habitats in southeastern Lake Michigan. These data have been used to assist decisions on licensing of the Cook Plant for operation, and will be used as a comparative base to detect any effects which operation of the plant may have on lake biota.

Benthic macroinvertebrates, the larger animals (ca. 2-20 mm in the longest dimension) living on or in the bottom of the lake, are particularly useful for detection of environmental changes because they spend most of their lives at the same location, thus integrating transient or variable events in the environment and recording these events as alterations in benthic species composition or abundance. Since most macroinvertebrates have life cycles approximately one year long, any impact which eliminates or reduces the abundance of a species may remain evident up to a year or more after it occurs. Moreover, zoobenthos depend almost entirely on sedimenting organic matter as the base of their food chain, and live among substances deposited over many months, years or decades on the bottom. Any change in overlying water which alters the amount or quality of sediments may be reflected in a time-averaged manner by zoobenthos responding to sediment quality.

The strategy for detection of ecological changes evident in composition of zoobenthos near the Cook Plant involves comparisons between zoobenthic species abundances at stations near the plant and at reference stations in similar habitats 3.2 km (2 miles) or more away. Preoperational studies have enabled descriptions of zoobenthos at both sets of stations, providing a two-fold basis for postoperational comparisons. Changes attributable to the plant can be distinguished from year-to-year changes due to other processes in the lake, because the plant's effect would occur only at nearby stations. The degree to which reference stations differ from those near the plant before operation has been established by preoperational surveys. Any apparent differences between pre- and postoperational abundances of the more numerous species or taxa can be tested using analysis of variance (Johnston 1974).

Also, patterns of zoobenthic species composition at stations near the plant will be examined subjectively for postoperational changes which may not occur evenly over the entire inner (near plant) zones. Many studies of Great Lakes benthos have substantiated the value of zoobenthic taxa in mapping

the extent of environmental degradation (e.g., Brinkhurst, Hamilton and Herrington 1968; Hiltunen 1969a; Howmiller and Beeton 1970).

Another group of studies at the Cook Plant is designed to assess the magnitude and impact of biological entrainment, i.e., passage of plants and animals suspended or living in lake water through the cooling system for condenser units. Water is pumped at a rate of $44 \text{ m}^3/\text{sec}$ ($7 \times 10^5 \text{ gal/min}$) through the condenser for Unit 1 of the Cook Plant. Shear forces in the 1.9 cm ($3/4$ inch) diameter condenser tubes are large and the temperature increases as much as 15°C above the ambient. Exploratory studies (Mozley 1973a, 1974) showed that a variety of zoobenthos were entrained, not only species which migrate above bottom at night such as *Pontoporeia* and *Mysis*, but also Chironomidae, Oligochaeta and numerous other taxa. Consequently, the numbers, kinds and diurnal and seasonal periodicity of entrained zoobenthos are being studied. If it appears that significant proportions of benthic populations are entrained, studies will be expanded to determine the mortality rate of entrained animals.

Investigations have continued since 1970, and results obtained prior to mid-1973 have already appeared in reports (Mozley 1974, etc.). Since the Cook Plant began to operate in January 1975, preoperational studies have ended and comparative, postoperational sampling is underway. The present report covers most of the remaining preoperational collections.

Beyond these specific concerns of potential environmental impact, zoobenthic studies at the Cook Plant include several peripheral projects which help evaluate sampling accuracy and the ability of benthic communities to recolonize disturbed habitats. As time and the taxonomic literature permit, each species of animal which occurs frequently in benthic samples is identified and analyzed to determine its reproductive and distributional patterns in the Cook survey area. Net tows were made in the lake to determine the densities of drifting zoobenthos which could reestablish populations in areas where catastrophic mortality has occurred (e.g., effects of severe storms and waves on shallow bottoms). Other studies are conducted to broaden understanding of the selectivity of survey sampling equipment (Mozley 1974).

Emphasis has been placed on studies of zoobenthic entrainment and "drift," or occurrence of benthic animals above bottom in 1974. Net tows were made day and night at several locations in the lake. Preliminary tests for

vertical and horizontal heterogeneity of benthos concentrations were conducted in the intake forebay of the Cook Plant. Crayfish impinged on the plant's traveling screens were identified and counted. Data from a special 24-hour study of the migratory cycle of zoobenthos were used to determine the proportions of benthic populations of each species which moved above bottom.

Taxonomic results are concerned primarily with *Pisidium* and Chironomidae. *Pisidium* (fingernail clams) from two surveys have been dissected, cleaned and compared with reference collections in the University of Michigan's Museum of Zoology to identify species over a wide range of depths. Adult and pupal Chironomidae have been collected and studied to confirm earlier identifications based only on larvae. Other additions to the register of indigenous species have come from benthic collections using 0.15-mm screens, midwater sampling of macroplankton, pumped samples from the intake forebay, scrapings from riprap (rock aprons) in front of the plant, and continuing identification of species from regular survey samples.

Methodological tests (compare Mozley 1974) continued with emphasis on numbers and kinds of zoobenthos which were not retained by the 0.5-mm screen used for regular surveys. These tests were prompted by the occurrence of large numbers of early developmental stages and small species of Naididae and Chironomidae in net tows for drifting zoobenthos which had not been encountered in benthic samples.

LITERATURE REVIEW

Environmental monitoring at power plants has provided almost all the recent information on Lake Michigan zoobenthos. Two consulting companies (Limnetics, Inc. and Industrial BIO-TEST Laboratories, Inc.), the Consumers Power Company, Michigan State University (Olson 1974) and the University of Michigan (this series) have issued reports consisting largely of extensive data lists, some comparisons of densities, seasonal abundances and species with previous studies, and conclusions as to whether significant changes have resulted or may result from operation of the plants.

All sites along the shoreline of Lake Michigan exhibit increasing

abundances of all zoobenthos combined, but decreasing abundances of Chironomidae (Diptera) with increasing distance from shore and depth. Taxa accounting for the increases are Tubificidae (Oligochaeta) at depths up to about 20-25 m, then *Pontoporeia affinis* (Amphipoda) accompanied by Sphaeriidae (Pelecypoda) and the lumbriculid oligochaete *Stylodrilus heringianus* at greater depths. Substrate plays a significant role in composition and abundance of benthic macroinvertebrates within a given depth interval, particularly when outcrops of bedrock or glacial lag deposits (cobbles and boulders) cover large proportions of the bottom (Limnetics, Inc. 1974; Olson 1974; Rains and Clevenger 1975). Solid substrates such as these are colonized by attached algae and an extremely diverse assemblage of small naidid oligochaetes and Chironomidae, which often total over 10,000 individuals per square meter (Rains and Clevenger 1975).

So far, no changes have been observed near operating power plants on Lake Michigan that have been interpreted as effects of increased heat (Brice 1975; Consumers Power Company 1975; WEPCO/WMPC 1975). Increased siltation resulting from construction activities eliminated much of the fauna associated with solid substrates, and supported increased numbers of burrowing Tubificidae at one site (Limnetics, Inc. 1974). At another, strong currents created by the cooling system discharges favored development of dense populations of *Hydropsyche*, a caddisfly (Trichoptera) (Limnetics, Inc. 1974).

Installation of structures to protect and channel the intake/discharge of the Ludington Pumped Storage Plant created new substrate in a sandy-bottomed area of the lake (Olson 1974). These solid substrates were colonized rapidly by an assemblage of zoobenthos quite different from those indigenous to the area. The new assemblage included two species of *Gammarus* (Amphipoda), *Aseellus* (Isopoda), *Physa* (Gastropoda), Trichoptera and the chironomid genera *Glyptotendipes*, *Thienemannimyia*-gr. and *Procladius*. Indigenous zoobenthos were dominated by tubificid oligochaetes and the amphipod *Pontoporeia*.

Rains (1971) reports zoobenthic composition and abundance in three in-shore areas of southern Lake Michigan, one of which is only 40 km south of the Cook Plant. There were no differences in species composition or distribution patterns between his results and those from the Cook Plant survey, except that more species have been recorded from the more extensive

Cook studies. Rains judged water quality by use of Tubificidae species composition, following Hiltunen (1967) and Howmiller and Beeton (1970), and the chironomid trophic index of Brinkhurst, Hamilton and Herrington (1968). The trophic index is double the ratio of chironomid larvae belonging to eutrophic-indicator genera to the total number of larvae. A value of 2 reflects complete absence of oligotrophic and mesotrophic indicators among the chironomids, while a value of 0 occurs when no eutrophic genera are represented. Genera are classified into the three indicator groups by reference to the largely European literature on lake typology (e.g., Brundin 1949). Rains found general indications of pollution or eutrophication at stations near Burns Ditch and Michigan City, and pointed out that the extent of eutrophication decreased with increasing depth and distance from shore by his criteria. Trophic index values conformed to indications based on tubificid species in his study, but we have chosen not to employ the trophic index in analyzing Cook Plant data. Such reductions in data are often based heavily on hypothetical concepts and imprecise taxonomy, and necessarily disregard useful information on occurrences and abundances of particular species. Moreover, the indicative significance of most Great Lakes chironomid species is inadequately known. Rains' conclusions that accelerated eutrophication is occurring in southern Lake Michigan, and that nearshore areas are already in the eutrophic range, are similar to the statements of Mozley and Garcia (1972) concerning the status of zoobenthos near the Cook Plant.

Studies at the Zion Nuclear Station have shown that large numbers of *Pontoporeia* are entrained into the once-through cooling system (Krueger 1975). Nearly all entrainment occurred during late December-early January, when *Pontoporeia* populations were near peak reproductive activity. Thermal elevations which occurred during plant passage were not harmful to *Pontoporeia* at that time of year because ambient temperatures were low. In summer, when ambient temperatures were high enough that passage through the plant was lethal to this amphipod, total entrainment was equivalent to the number of *Pontoporeia* occurring in 1.1 ha of lake bottom (2.3 acres). Krueger (1975) demonstrated that *Pontoporeia* will tolerate a temperature of 24C for up to two hours if returned immediately after exposure to an acclimation temperature of 10C. This is much higher than the lethal temperatures of 12C and 10.8C reported by Smith (1972) for 24- and 48-hour tests

with *Pontoporeia*. However, Krueger did observe heavy mortality of *Pontoporeia* during acclimation to 15C. Field data¹ show that substantial densities of this animal occur in areas of the lake where temperatures rise above 17C (Krueger 1975).

Earlier results of preoperational investigations of zoobenthos near the Cook Plant may be found in parts of the University of Michigan, Great Lakes Research Division Species Report 44 (IV, VI, VII, IX, X, XIII, XV, XVII, XVIII, XIX, and XX). The most recent and extensive presentation may be found in Special Report 51 of that series (Mozley 1974). It contains detailed information on methods, history of the study, and determination of the least detectable true change in abundances. The rationale for dividing the Cook Plant survey area into four depth zones and three regions is presented by Mozley (1973a). Results of Cook Plant zoobenthic surveys are presented in scientific journals by Mozley and Garcia (1972) and Mozley and Winnell (in press). Two reviews of the literature on Lake Michigan zoobenthos will appear soon (Mozley and Howmiller, in press; Mozley, in press). The latter adds opinions on the possible effects of increased use of inshore areas of Lake Michigan to absorb byproducts of energy conversion, and recommendations of research which is needed for evaluating their ecological significance.

REGULAR SURVEYS

METHODS

A section of Lake Michigan extending 11 km north, 11 km south and 11 km offshore from the Cook Plant was designated as the survey area. Parts of this area within 1.6 km (1 mile) of a central transect extending 11 km from the Cook Plant perpendicular to shore were defined as the region which might be affected by plant operation. Parts of the survey area 3.2 km (2 miles) or more from the central transect were defined as north and south reference regions. Each region was divided into four zones with boundaries set to approximate the 8-m, 16-m and 24-m isobaths. Offshore limits corresponded to a depth of about 33 m in the south, 39 m in the center and 44 m in the north of the survey area. Zone 0 was nearest shore, extending from 0 to 8 m,

¹ Alley, W. P. and S. C. Mozley. (submitted) Temperature tolerances of the burrowing amphipod *Pontoporeia affinis* in southern Lake Michigan as determined by field observations. Trans. Amer. Fish. Soc.

and zones 1 through 3 corresponded to successingly deeper intervals. Zones were defined in order to establish a revised, partially randomized sampling design for major surveys beginning in July 1972. Distributions of common benthic macroinvertebrates (Mozley and Garcia 1972; Mozley 1973a) guided the definition of zones.

Four sampling designs have been employed for Cook Plant benthic surveys (Ayers and Seibel 1973), three of them in 1973 and 1974 (Figs. 1 and 2a and b). The October 1973 and April 1974 major surveys were the last two of six surveys conducted on the partially randomized design (Fig. 1). Three stations were selected at random in each of 12 areas, corresponding to the four depth zones in the three regions of the survey area. Reference regions were restricted to the outermost 3.2 km of the areas defined in the foregoing paragraph. At the nine stations at depths less than 8 m (zone 0) five full-sized ponar grab casts were made at each station. Three one-third sized ponar casts (Mozley and Chapelsky 1973) were made at each of the 27 deeper stations. Larger samples were collected at shallow stations because macroinvertebrates were less abundant and their distribution was more patchy there (Mozley 1974). The July and October 1974 major surveys were taken on a reduced grid selected from the set of 45 stations used from July 1970 to April 1972 (Fig. 2a). At each station less than 8 m deep, four one-third sized ponar casts were taken, but only two one-third sized casts were collected at deeper stations. Stations were selected so that each depth zone was represented by five stations in the inner, or central region, and five stations in the two outer or reference regions, combined. The deepest zone was not sampled on these surveys so that more effort could be devoted to entrainment studies (Ayers and Seibel 1973). Short surveys, which were intended primarily to provide more detailed information about seasonal changes in abundance of macroinvertebrates in the center of the survey area, consisted of 11 stations (Fig. 2b). Five full-sized ponar casts were taken at stations less than 8 m deep, and three one-third sized ponar casts were taken at deeper stations.

The contents of each grab cast were examined for description of the approximate texture of sediments (gravel, coarse sand, medium sand, fine sand, silt, soft clay, compacted clay and organic detritus) then processed to remove macroinvertebrates. The sample was placed in a funnel-shaped hopper mounted on the railing of the ship, and stirred to remove lumps and

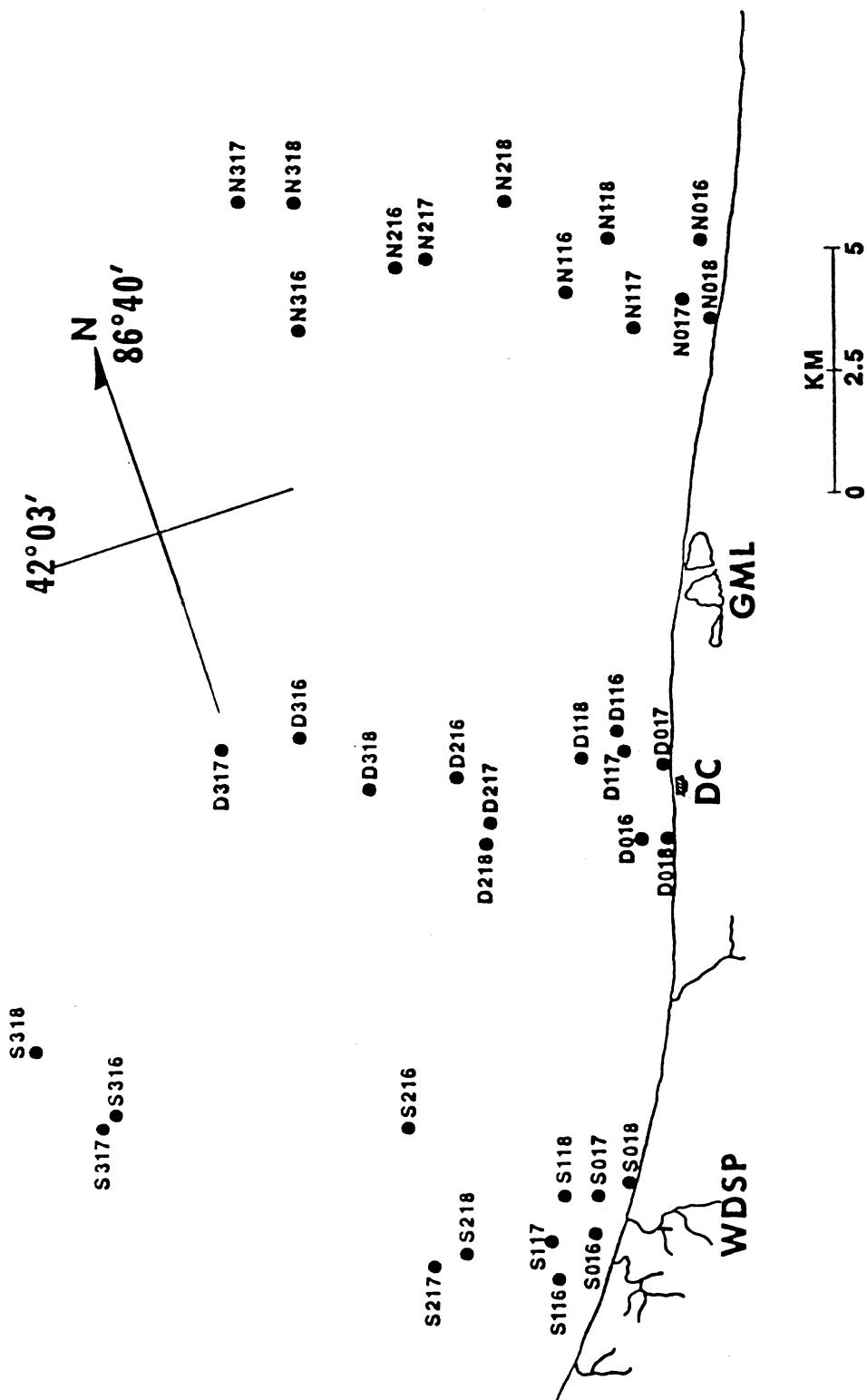


FIG. 1. Stations of the April 1974 major survey of zoobenthos, an example of the partially randomized sampling design. WDSP = Warren Dunes State Park, DC = D. C. Cook Nuclear Plant, GML = Grand Marais Lakes.

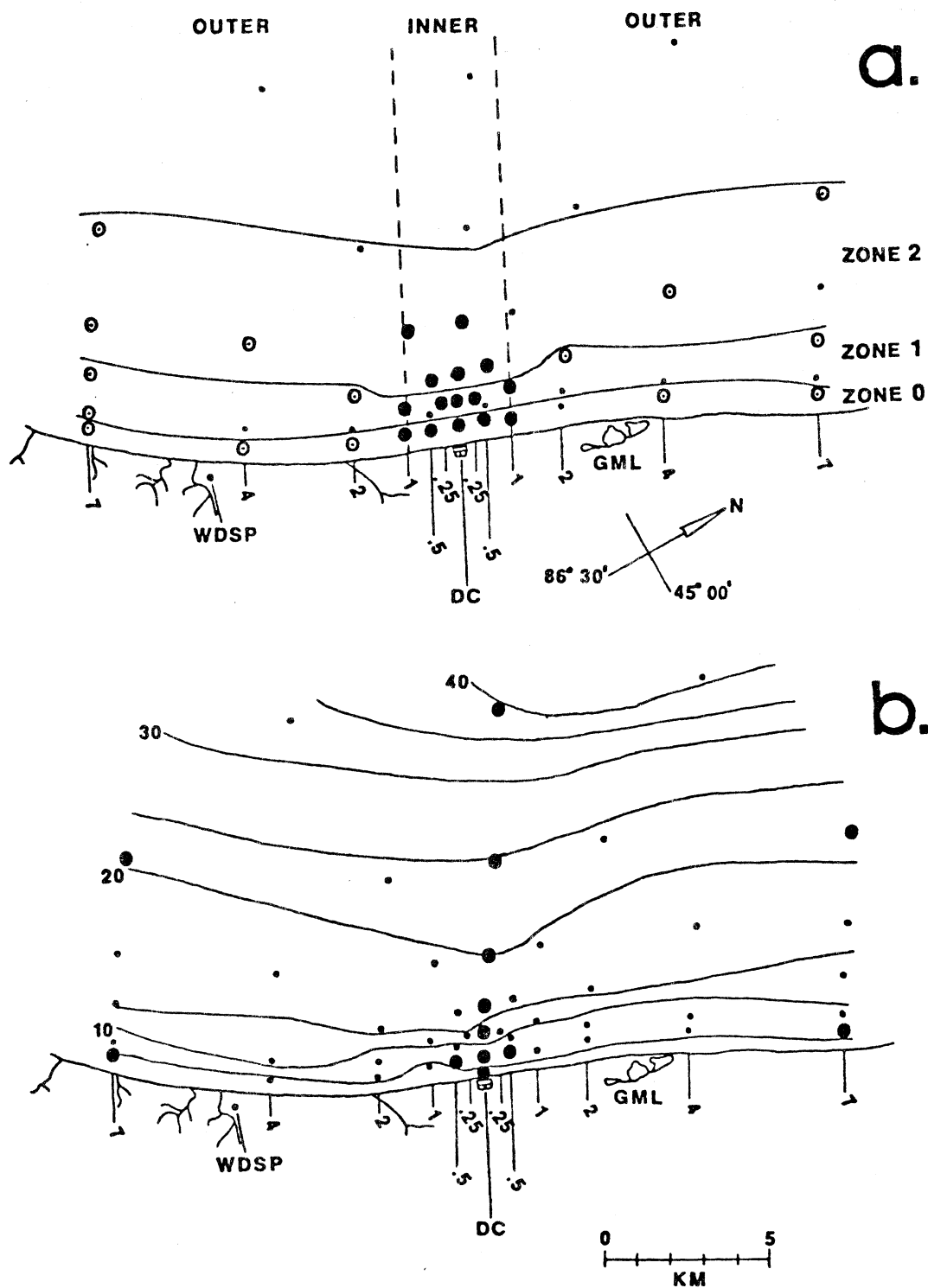


FIG. 2. Stations used on major surveys of zoobenthos in July and October 1974 (a) and on 1974 short surveys (b).

suspend the contents of the grab in water (Fig. 3). The suspension was poured out through the spout before animals or sediment finer than medium sand could settle out. Material remaining in the hopper was washed at least three additional times in this manner, or until no macroinvertebrates could be seen in the hopper. A cylindrical screen with 0.5-mm mesh openings was used to screen animals and detritus from the suspension. The screen residue was rinsed and transferred into a jar attached to the lower end of the screen. When dominant sediment grain size was finer than medium sand, all material was rinsed from the hopper onto the screen.

Preserved residues (5% formalin) were examined at a magnification of at least 16X under a dissecting microscope for the picking and sorting operations. *Pontoporeia affinis* was distinguished from other amphipods and separated into classes according to length and reproductive status. Several other taxa were also identified to species under low magnification including *Sphaerium*, *Stylodrilus* and *Mysis*. Remaining macroinvertebrates were sorted only to higher taxonomic levels such as Tubificidae, Naididae, *Pisidium* or Chironomidae. The resulting data will be designated as "major taxa" information here. Subsequently, individuals of Chironomidae, Tubificidae and Naididae were mounted on slides and identified to species (when-ever possible) at a magnification of 400X. Only specimens from depths less than 16 m and surveys prior to 1974 have been identified to the lower level at this time. *Pisidium* species from two surveys have been identified, which required that the flesh be removed from shells in an ultrasonic cleaning bath. Small invertebrates in several taxa (Nematoda, Harpacticoidea, Cladocera, Ostracoda) were often noticed in macroinvertebrate collections, but have not been identified or counted.

REGIONAL ABUNDANCES OF MAJOR TAXA BY SEASON AND DEPTH

Data from the systematic-random design employed in major surveys from July 1972 to April 1974 (Mozley 1973a) are graphed to illustrate gradients in zoobenthos parallel to shore, and the interactive effects of time and depth along this gradient. The polygons for July 1972 through July 1973 appeared in last year's report (Mozley 1974), but are repeated here for comparison with remaining surveys which were conducted with this design.

Means and standard errors (\bar{Sx}) are given for each zone (Tables 1 and 2)

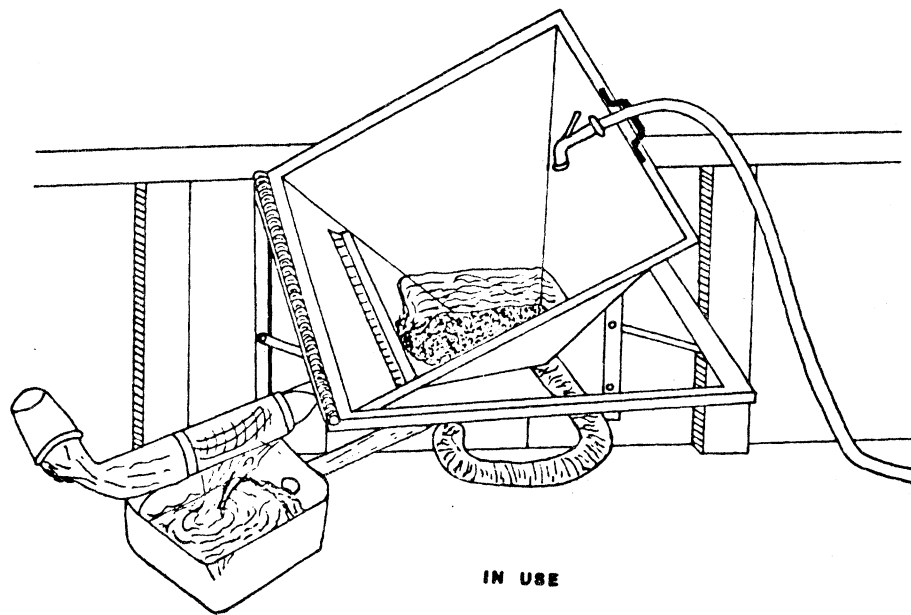
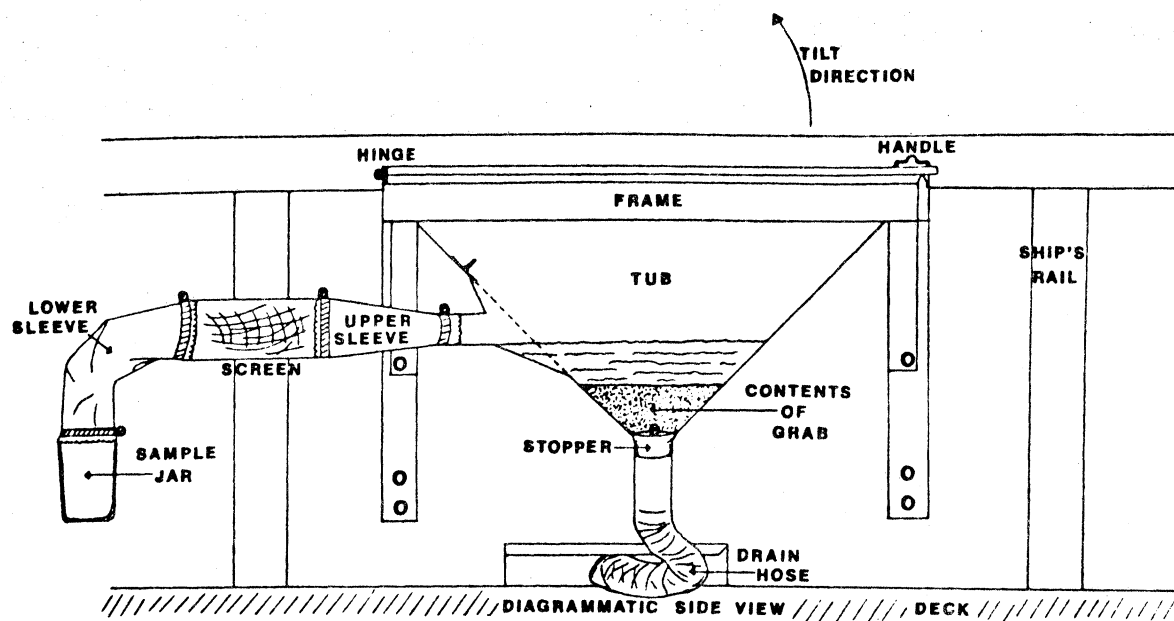


FIG. 3. Benthic sample processing device. The funnel-shaped hopper is shown above just after the contents of a grab have been introduced. Below, the device is shown in operation as suspended materials flow out the spout to be strained on the cylindrical screen.

TABLE 1. Station means and zone means and standard errors¹ for major taxa of zoobenthos in the October 1973 major survey. Zone means are based on station means. Units are numbers/m².

Stat.	Ponto.	Tubif.	Naid.	Stylo.	S. nit.	S. str.	Pisid.	Chiro.	Hirud.	Oper.	Pulm.	Other	Total Animals
N013 (3)	0	0	0	0	0	0	0	449	0	0	0	0	449
N014 (0)				---	NO DATA ---								
N015 (5)	12.2	16.3	0	0	0	0	40.8	180	12.2	0	0	0	262
Zone 0	6.1±6.1	8.2±8.2	0	0	0	0	20.4±20.4	315±135	6.1±6.1	0	0	0	356±93.5
N113 (3)	2060	485	40.4	101	20.2	0	970	283	0	20.2	20.2	101	4102
N114 (3)	848	2202	20.2	121	40.4	0	505	505	20.2	0	40.4	0	4302
N115 (3)	1333	343	141	80.8	0	0	303	101	20.2	0	0	40.4	2362
Zone 1	1414±352	1010±597	67.2±37.4	101±11.6	20.2±11.7	0	593±197	296±117	13.5±6.73	6.7±6.73	20.2±11.7	47.1±29.4	3589±616
N213 (3)	7171	182	242	101	40.4	0	242	182	0	20.2	0	20.2	8201
N214 (3)	8201	1313	0	2283	80.8	0	2283	101	0	20.2	40.4	0	14322
N215 (3)	3091	3293	60.6	1778	40.4	20.2	808	303	0	40.4	20.2	0	9455
Zone 2	6154±1560	1596±909	101±72.7	1387±659	53.8±13.5	6.73±6.73	1111±608	195±58.7	0	26.9±6.73	20.2±11.7	6.73±6.73	10658±1867
N313 (3)	12120	7090	0	3656	0	0	4202	60.6	0	0	0	20.2	27149
N314 (3)	8888	3335	0	3333	40.4	0	3151	121	20.2	0	0	0	19088
N315 (3)	6767	1454	0	1757	0	20.2	2161	60.6	20.2	0	0	0	12240
Zone 3	9258±1556	4026±1645	0	2915±587	13.5±13.5	6.73±6.73	3171±589	80.7±20.1	13.5±6.73	0	0	6.73±6.73	19491±4309

¹ 95% confidence interval = Student's "t" times the standard error. $t_{.05} (2 \text{ d.f.}) = 4.3$.

TABLE 1 continued.

Stat.	Ponto.	Tubif.	Naid.	Stylo.	S. nft.	S. str.	Pisid.	Chiro.	Hirud.	Oper.	Pula.	Other	Total Animals
D013 (5)	81.6	1946	192	12.2	4.08	69.4	273	1089	24.5	85.7	0	32.6	3810
D014 (5)	0	0	0	0	0	0	0	0	0	0	0	0	0
D015 (5)	16.3	8.16	4.08	0	4.08	0	4.08	208	8.16	0	0	0	253
Zone 0	32.6±24.9	651±647	65.4±63.3	4.07±4.07	2.72±1.36	23.1±23.1	92.4±90.3	432±334	10.9±7.21	28.6±28.6	0	10.±10.9	1356±1230
D113 (3)	444	36744	60.6	182	101	20.2	1475	545	525	121	20.2	40.4	40278
D114 (3)	1293	5535	60.6	60.6	101	40.4	1596	1071	60.6	121	0	20.2	9959
D115 (3)	283	4141	40.4	20.2	60.6	0	2283	1495	162	424	0	283	9192
Zone 1	673±313	15473±10643	53.9±6.73	87.6±48.6	87.5±13.5	20.2±11.7	1785±252	1037±275	249±141	222±101	6.73	6.73	114±84.4
D213 (3)	4686	2101	0	6706	202	0	1555	60.6	0	60.6	0	0	15371
D214 (3)	7030	4262	0	6444	323	20.2	2424	40.4	0	80.8	0	40.4	20665
D215 (3)	3434	19271	101	1293	485	20.2	2545	121	101	182	0	0	27553
Zone 2	5050±1054	8545±5399	33.7±33.7	4814±1762	337±82.0	13.5±6.73	2175±312	74.0±24.2	33.7±33.7	108±37.6	0	13.0±13.5	21197±3527
D313 (3)	4888	8686	0	2565	222	0	6807	101	0	0	0	0	23269
D314 (3)	5232	8848	0	3676	465	0	7131	80.8	0	0	0	0	25433
D315 (3)	11554	6666	0	4343	40.4	0	7030	162	0	0	0	0	29795
Zone 3	7225±2167	8067±702	0	3528±519	242±123	0	6989±95.7	115±24.4	0	0	0	0	26166±1919

TABLE 1 continued.

Stat.	Ponto.	Tubif.	Naid.	Stylo.	S. nit.	S. str.	Pisid.	Chiro.	Hirud.	Oper.	Pulm.	Other	Total Animals
S013 (5)	114	979	53.0	8.16	40.8	24.5	249	1563	32.6	131	4.08	49.0	3248
S014 (5)	4.08	0	0	0	0	0	0	57.1	0	8.16	0	0	69.3
S015 (5)	85.7	1452	147	0	4.08	57.1	290	1530	53.0	77.5	0	8.16	3705
Zone 0	67.9±33.0	810±428	66.7±43.0	2.72±2.72	15.0±13.0	27.2±16.5	180±90.6	1050±497	28.5±15.4	72.2±35.6	1.36±1.36	19.0±15.2	2341±1143
S113 (3)	687	20927	60.6	80.8	0	0	2060	1394	101	0	0	20.2	25331
S114 (3)	1050	5636	20.2	20.2	0	0	828	707	80.8	0	0	20.2	8362
S115 (3)	162	990	101	0	20.2	0	525	747	121	121	0	60.6	2848
Zone 1	633±258	9184±6023	60.6±23.3	33.7±24.3	6.73±6.73	0	1138±469	949±223	101±11.6	40.3±40.3	0	33.7±13.5	12180±6765
S213 (3)	7333	4141	0	3192	101	0	3676	40.4	20.2	20.2	20.2	0	18544
S214 (3)	6161	2505	101	4222	1515	80.8	4242	60.6	60.6	283	40.4	20.2	19292
S215 (3)	2990	11494	0	7696	626	0	6727	60.6	20.2	20.2	0	0	29634
Zone 2	5495±1297	6047±2764	33.7±33.7	5037±1363	747±413	27.0±27.0	4882±937	53.9±6.73	33.7±13.5	108±87.6	20.2±11.7	6.73±6.73	22491±3579
S313 (3)	9191	5979	0	3575	0	0	6363	60.6	0	0	0	0	25169
S314 (3)	8969	5797	0	4060	0	0	4767	101	0	0	0	20.2	23714
S315 (3)	5292	5191	0	3959	20.2	0	4848	20.2	0	0	0	0	19330
Zone 3	7817±1264	5656±238	0	3865±148	6.73±6.73	0	5326±519	60.6±23.3	0	0	0	6.73±6.73	22738±1755

TABLE 2. Station means and zone means and standard errors¹ for major taxa of zoobenthos in the April 1974 major survey. Zone means are based on station means. Units are numbers/m².

Stat.	Ponto.	Tubif.	Naid.	Stylo.	S. nit.	S. str.	Pisid.	Chiro.	Hirud.	Opet.	Pulm.	Other	Total Animals
N016 (5)	0	36.7	0	0	0	0	0	77.5	0	0	0	0	114
N017 (5)	0	12.2	0	0	0	0	0	200	4.08	0	0	0	216
N018 (5)	4.08	8.16	0	0	0	0	0	28.6	0	0	0	0	40.8
Zone 0	1.36±1.36	19.0±8.91	0	0	0	0	0	102±51.0	1.36±1.36	0	0	0	124±50.8
N116 (3)	1414	1010	0	667	20.2	40.4	707	343	0	0	0	0	4202
N117 (3)	0	242	0	20.2	0	0	121	182	80.8	0	0	0	646
N118 (3)	727	1151	0	242	20.2	0	364	404	20.2	20.2	0	0	2949
Zone 1	714±408	801±282	0	310±190	13.5±6.73	13.5±13.5	397±170	310±66.2	33.7±24.3	6.73±6.73	0	0	2599±1041
N216 (3)	2889	3575	0	4606	444	0	2303	121	20.2	162	0	0	14120
N217 (3)	80.8	364	0	263	20.2	0	60.6	40.4	0	20.2	0	0	849
N218 (3)	40.4	1333	0	444	20.2	0	202	182	0	40.4	0	0	2262
Zone 2	1003±943	1757±951	0	1771±1468	161±141	0	855±725	114±41.0	6.73±6.73	74.2±46.3	0	0	5742±4208
N316 (3)	6504	3474	0	3596	80.8	20.2	5191	182	20.2	0	0	20.2	19088
N317 (3)	5939	6545	0	6100	40.4	0	4767	404	0	0	0	20.2	23816
N318 (3)	5999	4404	0	5838	121	0	11272	364	20.2	0	0	20.2	28038
Zone 3	6147±179	4808±909	0	5178±1795	80.7±23.3	6.73±6.73	7077±2101	317±68.3	13.5±6.73	0	0	20.2±0	23648±2585

¹ 95% confidence interval = Student's "t" times the standard error. $t_{.05} (2 \text{ d.f.}) = 4.3$.

TABLE 2 continued.

Stat.	Ponto.	Tubif.	Naid.	Stylo.	S. nit.	S. str.	Pisid.	Chiro.	Hirud.	Oper.	Pulm.	Other	Total Animals
D016 (5)	0	12.2	0	0	0	0	0	73.4	0	0	0	0	85.6
D017 (5)	0	0	0	0	0	0	0	4.08	0	0	0	0	4.08
D018 (5)	0	8.16	0	0	0	0	0	4.08	0	0	0	0	12.2
Zone 0	0	6.79±3.59	0	0	0	0	0	27.2±23.1	0	0	0	0	34.0±25.9
D116 (3)	0	0	0	0	0	0	20.2	121	0	0	0	0	141
D117 (3)	40.4	182	0	20.2	0	0	101	343	0	0	0	0	687
D118 (3)	808	4626	0	747	40.4	0	667	343	20.2	40.4	40.4	0	7332
Zone 1	283±263	1603±1513	0	256±246	13.5±13.5	0	263±203	269±74.0	6.73±6.73	13.5±13.5	13.5±13.5	0	2721±2311
D216 (3)	1555	1959	0	626	40.4	0	101	60.6	0	20.2	0	0	4362
D217 (3)	263	505	0	60.6	20.2	0	121	20.2	0	0	0	0	990
D218 (3)	202	12403	0	1030	384	20.2	2868	283	60.6	141	0	0	17392
Zone 2	673±441	4956±3747	0	572±281	148±118	6.73±6.73	1030±919	121±81.7	20.2±20.2	53.7±44.0	0	0	7581±5001
D316 (3)	2060	10019	0	3232	40.4	0	7636	283	0	20.2	20.2	0	23311
D317 (3)	3717	6141	0	4343	20.2	0	4949	424	0	0	0	0	19594
D318 (3)	5636	5494	0	7353	101	0	4181	202	0	40.4	20.2	0	23028
Zone 3	3804±1033	7218±1413	0	4976±1231	53.9±24.3	0	5589±1047	303±64.9	0	20.2±11.7	13.5±6.73	0	21978±1195

TABLE 2 continued.

Stat.	Ponto.	Tubif.	Naid.	Stylo.	S. nit.	S. str.	Pisid.	Chitro.	Hirud.	Oper.	Pulm.	Other	Total Animals
S016 (5)	0	12.2	0	0	0*	0	12.2	65.3	0	0	0	4.08	93.8
S017 (5)	0	261	0	0	4.08	0	8.16	1501	0	4.08	0	0	1778
S018 (5)	0	0	0	0	0	0	0	12.2	0	0	0	0	12.2
Zone 0	0	91.1±85.0	0	0	1.36±1.36	0	6.79±3.59	526±488	0	1.36±1.36	0	1.36±1.36	628±575
S116 (3)	0	505	0	0	0	0	101	626	20.2	40.4	0	0	1293
S117 (3)	141	990	0	141	0	20.2	323	747	20.2	20.2	20.2	40.4	2443
S118 (3)	101	323	0	0	0	0	20.2	586	0	0	0	0	1030
Zone 1	80.7±42.0	606±199	0	47.0±47.0	0	6.73±6.73	148±90.5	653±48.4	13.5±6.73	20.2±11.7	0	13.5±13.5	1589±434
S216 (3)	1293	3495	0	6464	444	60.6	4202	283	20.2	80.8	0	0	16343
S217 (3)	1192	3313	0	788	40.4	0	465	202	0	20.2	20.2	0	6041
S218 (3)	465	747	0	80.8	0	0	283	60.6	0	20.2	0	0	1657
Zone 2	983±261	2518±887	0	2444±2020	161±142	20.2±20.2	1650±1277	182±65.0	6.73±6.73	40.4±20.2	6.73±6.73	0	8013±4353
S316 (3)	1495	6666	0	3979	121	0	7050	242	0	20.2	0	20.2	19593
S317 (3)	1293	8161	0	3414	20.2	0	7050	101	0	0	0	0	20039
S318 (3)	4949	7979	0	4020	20.2	0	4606	364	0	20.2	0	0	21958
Zone 3	2579±1186	7602±471	0	3804±196	53.8±33.6	0	6235±815	236±76.0	0	13.5±6.73	0	6.73±6.73	20530±726

and graphically (Figs. 4-12). The bracketed lines within the polygons show one standard error at the horizontal scale of the means. Outlines of the polygons were derived by connecting means in adjacent zones, assuming 0 animals/m² at the shoreline, and extending the zone 3 mean straight to the lower edge of the zone.

Total numbers of benthic macroinvertebrates per square meter increased with depth in every survey, except in the south reference region ("S", Fig. 4). Higher numbers at intermediate depths there reflected dense Tubificidae populations. Abundance estimates were generally greater, month for month, in 1973 than in 1972 or 1974 surveys. The size of the standard error relative to the mean decreased with increasing depth, illustrating the more even distribution of deepwater species and the more homogeneous nature of the habitat. In many cases, the actual value of the standard error decreased with increasing depth also.

The amphipod *Pontoporeia affinis* was regularly more numerous in the north reference region ("N"), and was the most abundant major taxon in zones 2 and 3 of that region (Fig. 5). In the south reference region, however, oligochaetes in the family Tubificidae and *Stylodrilus* were usually more numerous. The central region ("D") contained populations intermediate between those of reference regions. Standard errors were smaller relative to the means for *Pontoporeia* than for most other taxa. *Pontoporeia* abundance increased in deeper zones. This amphipod was rarely represented by more than a few specimens in zone 0 (exceptions occurred in N and D regions in April 1973).

Stylodrilus heringianus was usually more numerous in the D and S regions (Fig. 6). The change in horizontal scales (see insets) with this figure reflects the normally lower numbers of *Stylodrilus* in comparison to Tubificidae and *Pontoporeia*. *Stylodrilus* was more stable than these other taxa numerically, however, and became more prominent in the benthos when other taxa reached minimums of seasonal or year-to-year fluctuations. This lumbriculid oligochaete was rarely collected shallower than 16 m at the Cook Plant.

Tubificidae, composed primarily of several *Limnodrilus* and *Potamothrix* species and *Tubifex tubifex*, were the most variable taxa in time and space (note broad standard errors in Fig. 7). They were always more numerous in regions D and S, but fluctuated more than an order of magnitude from

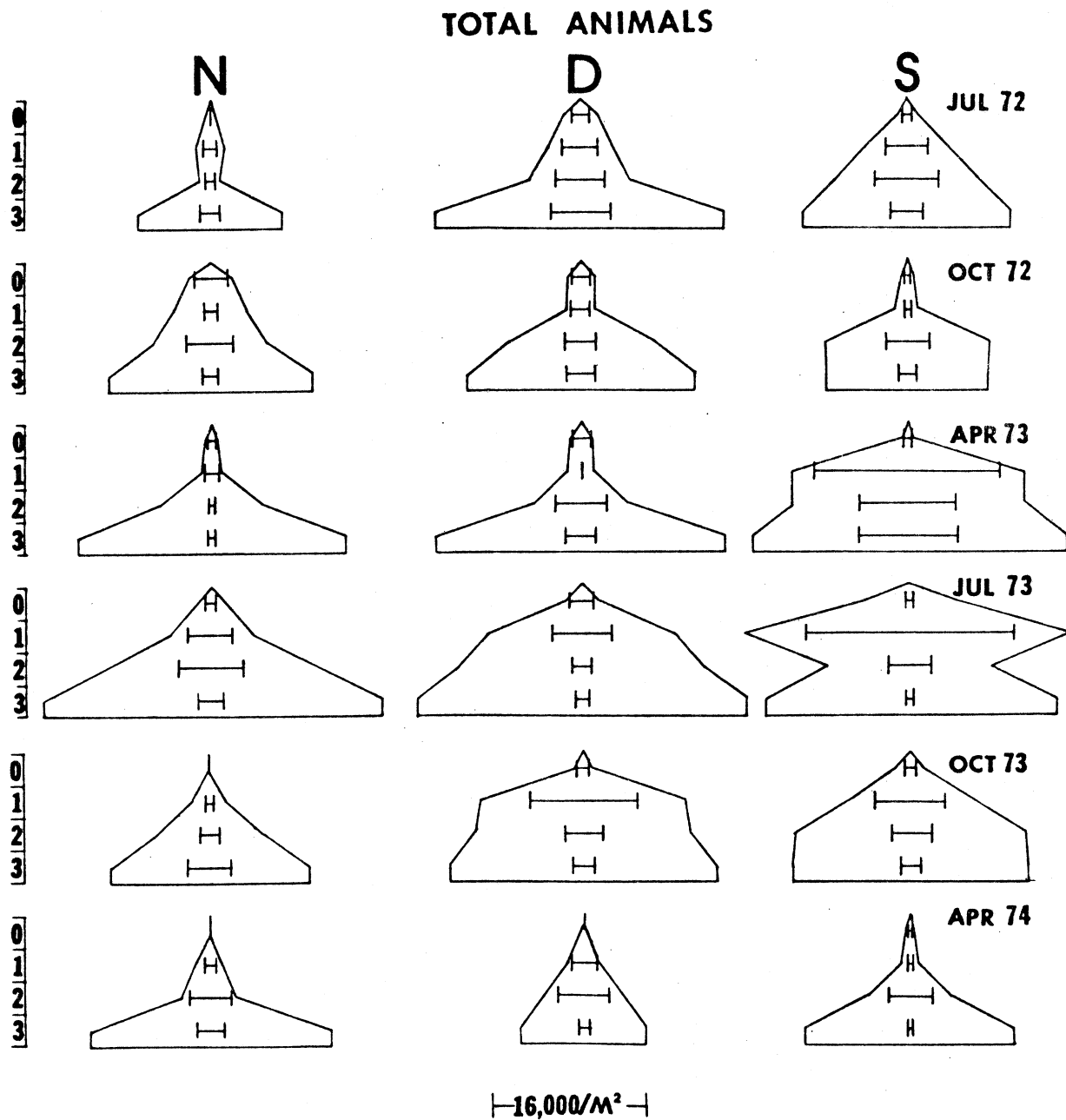


FIG. 4. Mean (polygon width) and one standard error (inset bars) for total animals within four depth zones (0-3) and three regions (N, D, S) for six major surveys of Lake Michigan near the Cook Plant.

PONTOPOREIA

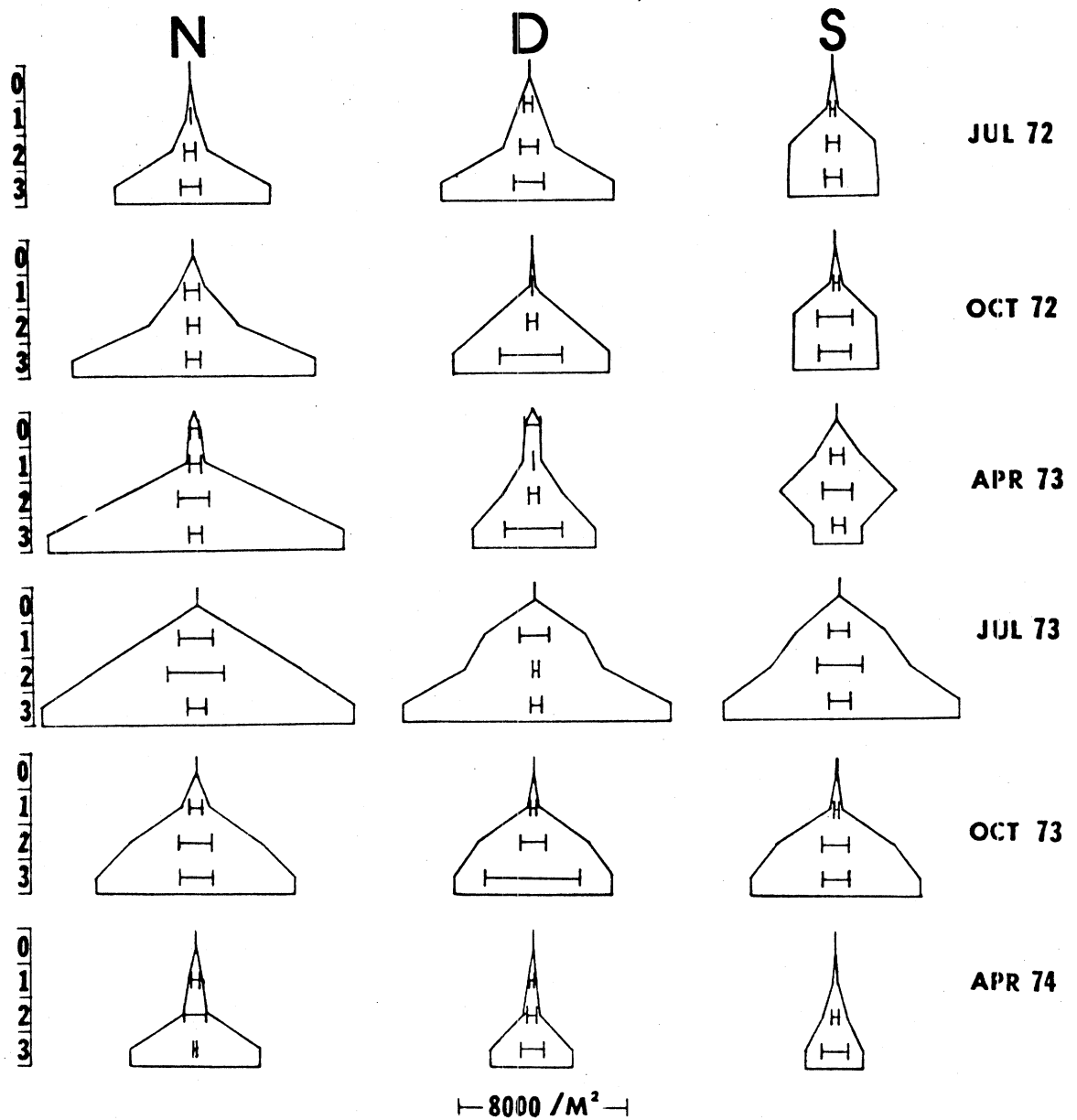


FIG. 5. Mean (polygon width) and one standard error (inset bars) for *Pontoporeia affinis* within four depth zones (0-3) and three regions (N, D, S) for six major surveys of Lake Michigan near the Cook Plant.

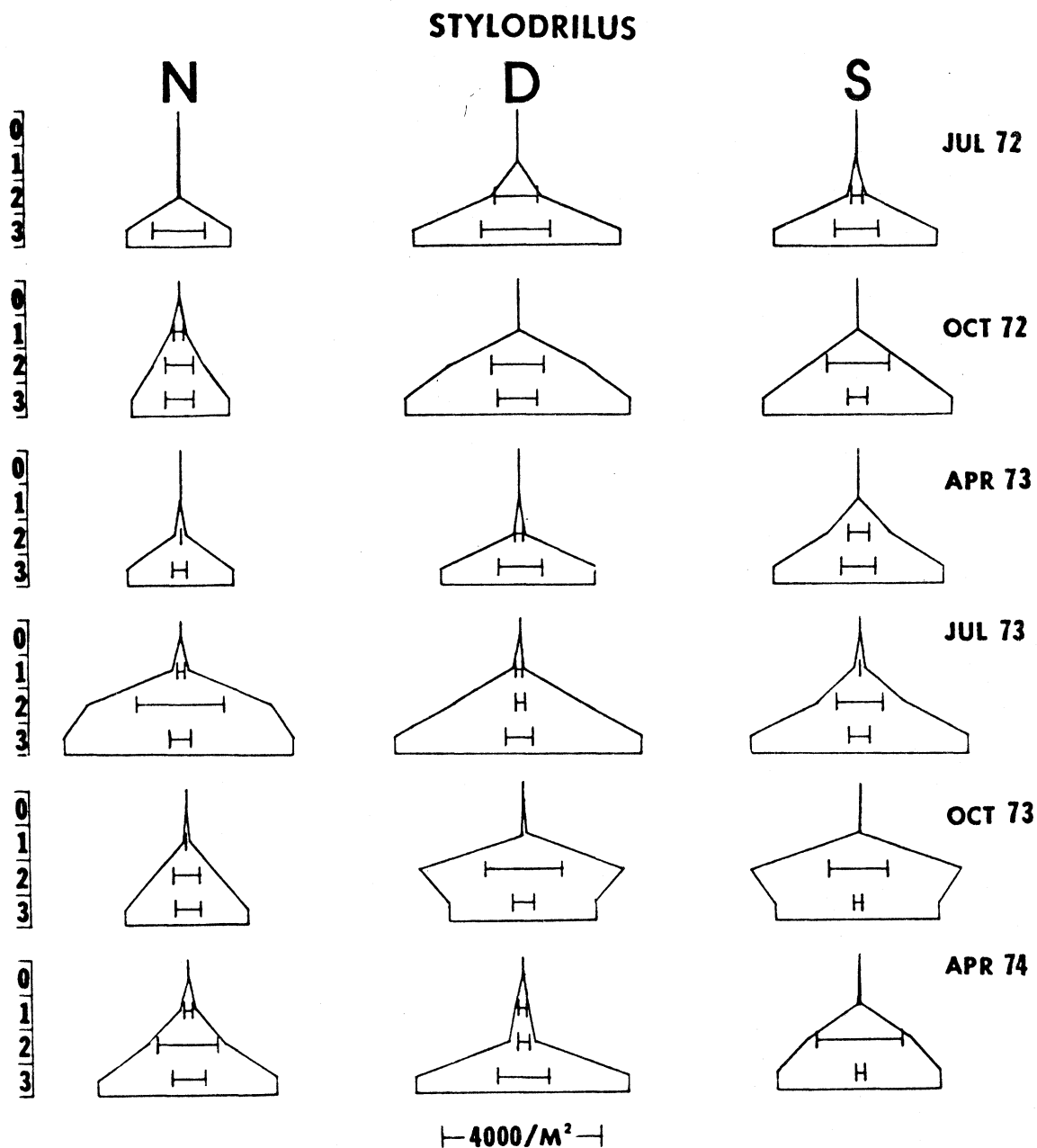


FIG. 6. Mean (polygon width) and one standard error (inset bars) for *Stylodrilus heringianus* within four depth zones (0-3) and three regions (N, D, S) for six major surveys of Lake Michigan near the Cook Plant.

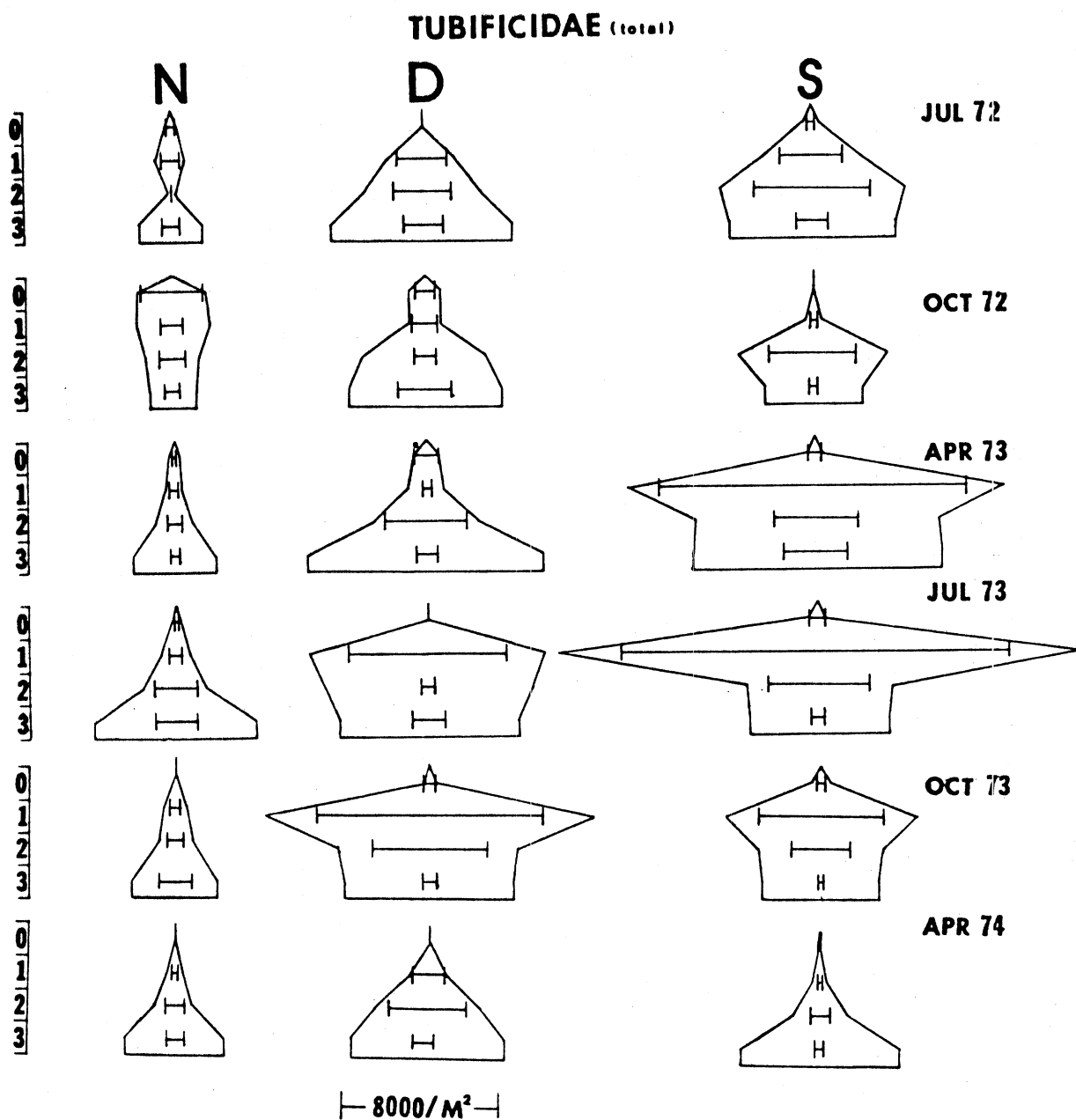


FIG. 7. Mean (polygon width) and one standard error (inset bars) for Tubificidae within four depth zones (0-3) and three regions (N, D, S) for six major surveys of Lake Michigan near the Cook Plant.

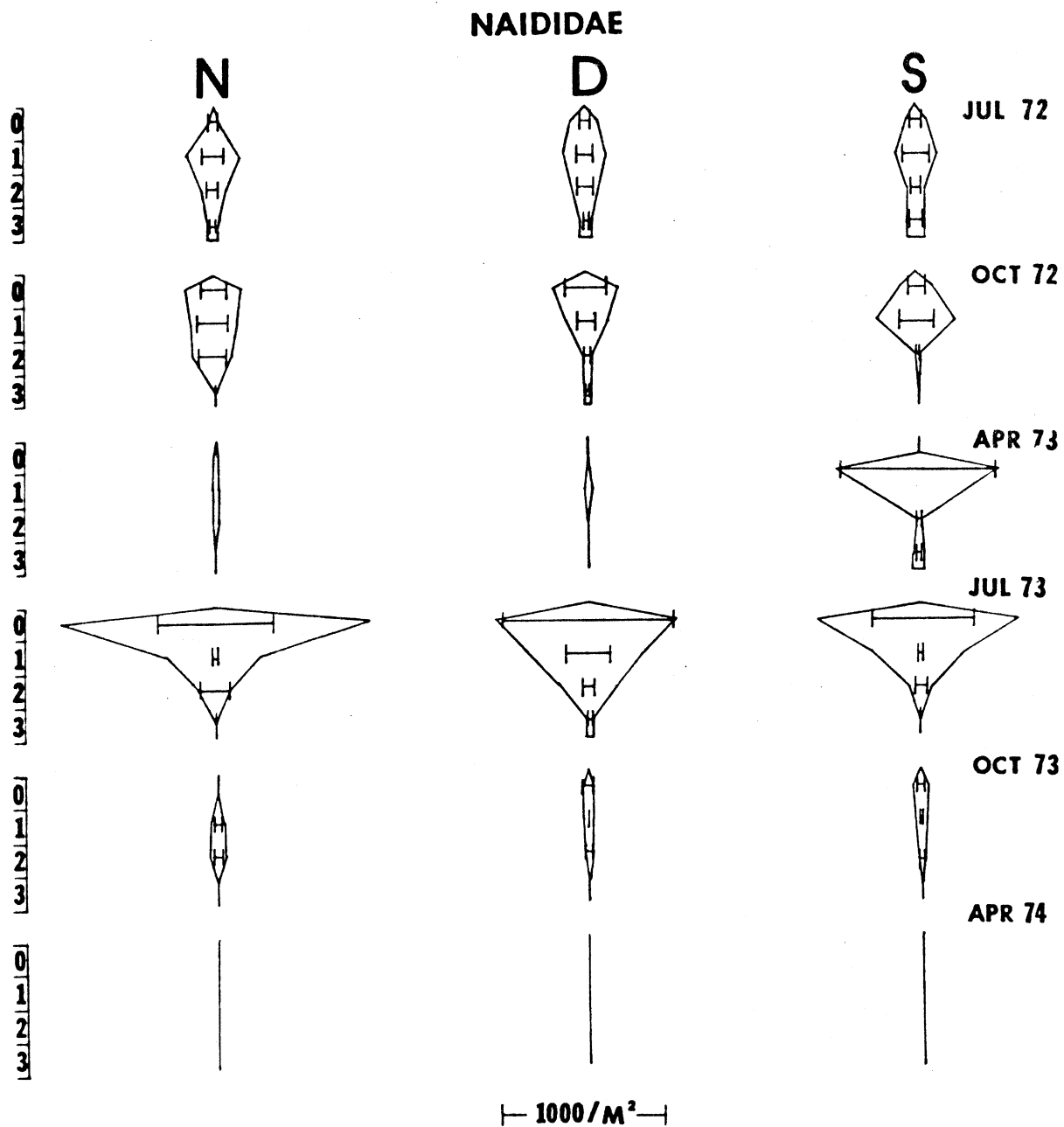


FIG. 8. Mean (polygon width) and one standard error (inset bars) for Naididae within four depth zones (0-3) and three regions (N, D, S) for six major surveys of Lake Michigan near the Cook Plant.

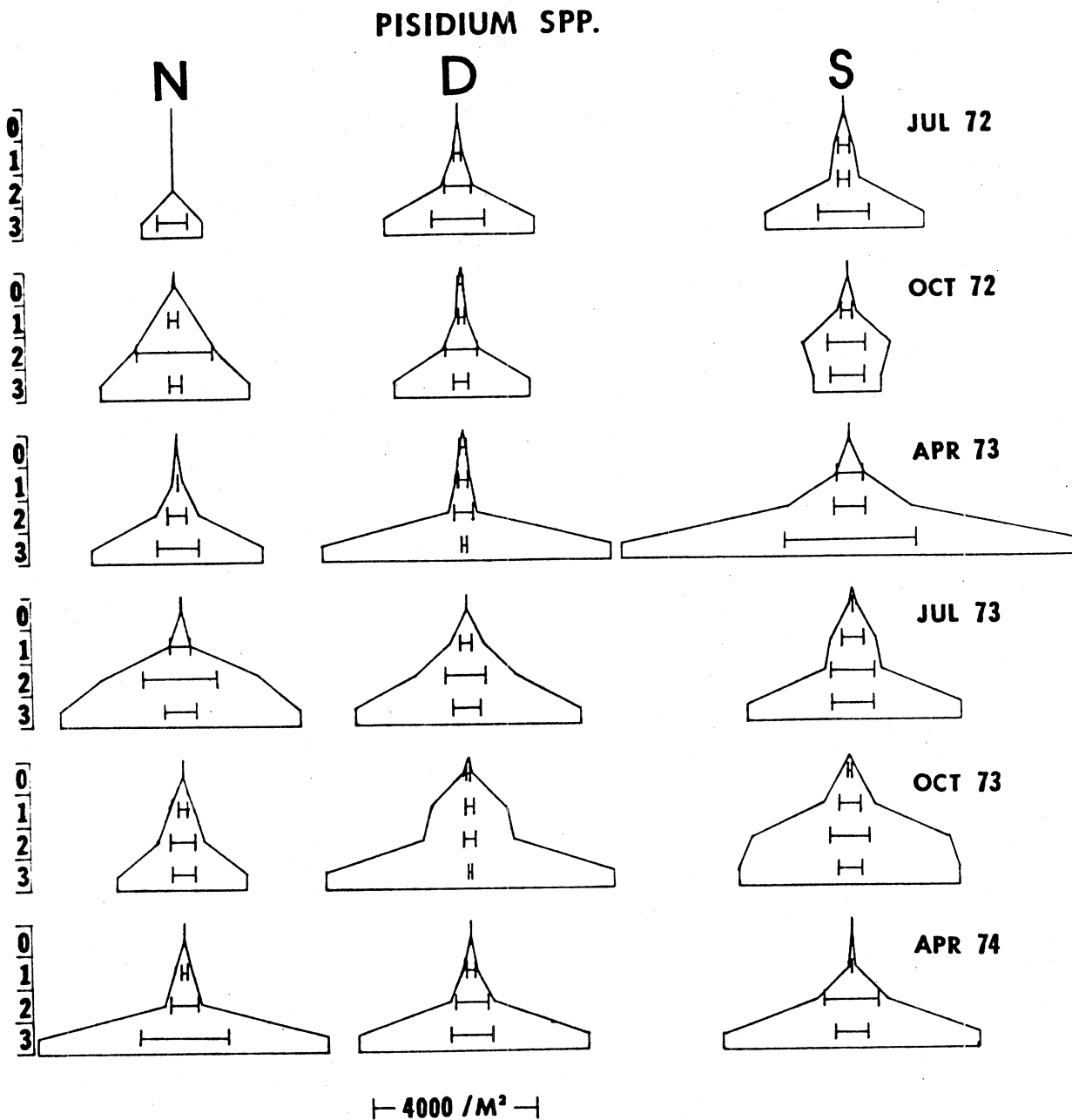


FIG. 9. Mean (polygon width) and one standard error (inset bars) for *Pisidium* spp. within four depth zones (0-3) and three regions (N, D, S) for six major surveys of Lake Michigan near the Cook Plant.

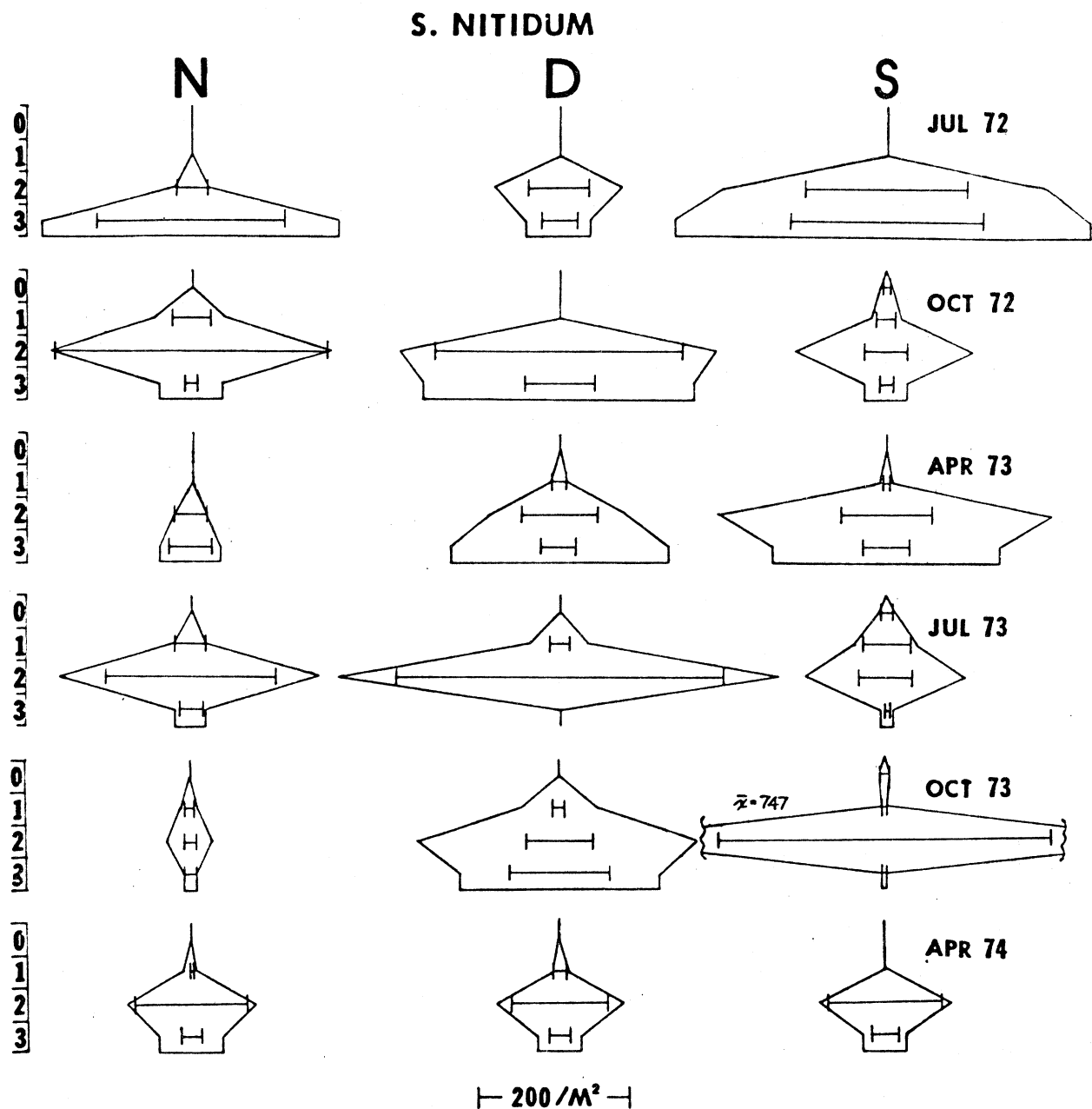


FIG. 10. Mean (polygon width) and one standard error (inset bars) for *S. nitidum* within four depth zones (0-3) and three regions (N, D, S) for six major surveys of Lake Michigan near the Cook Plant.

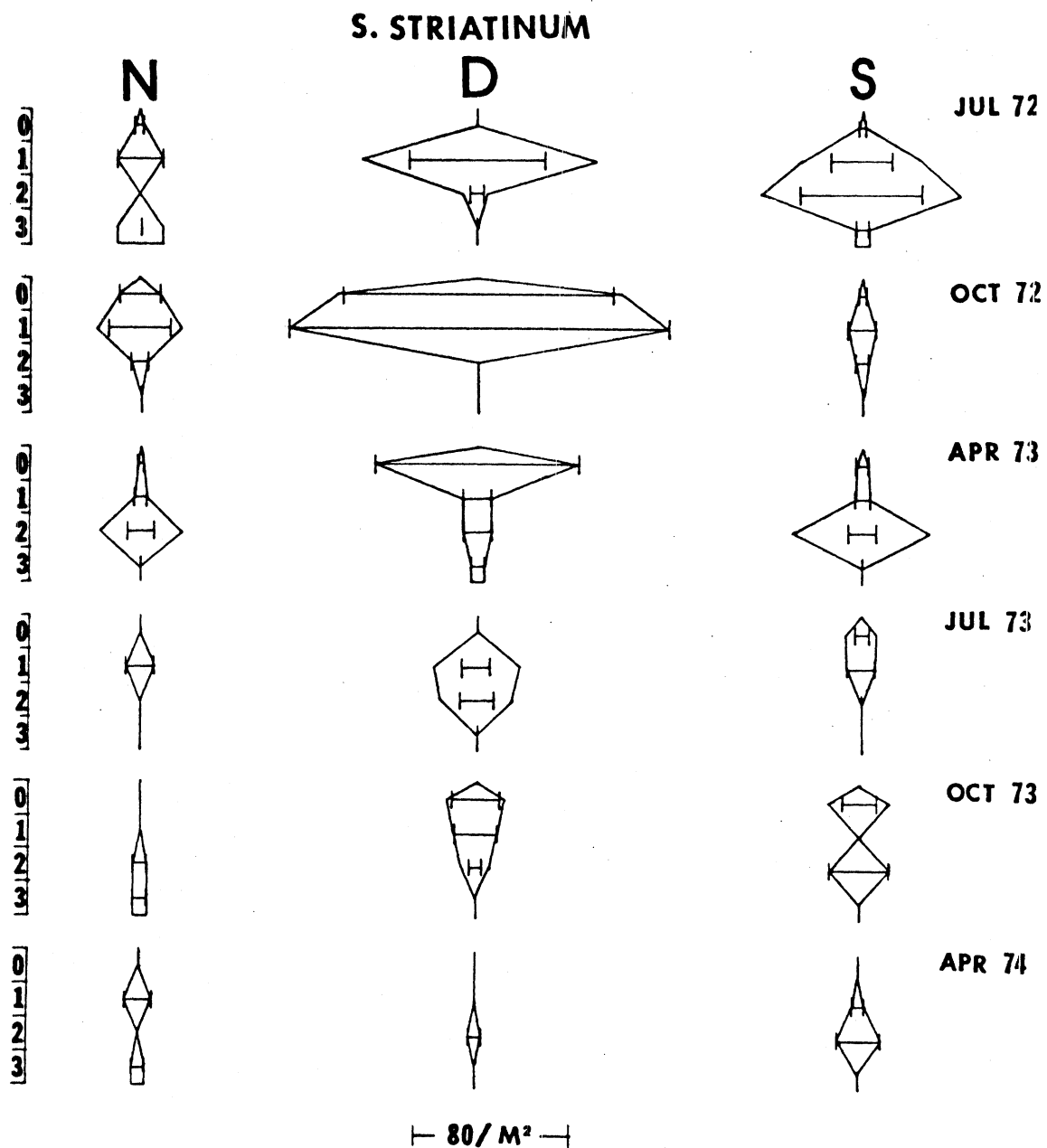


FIG. 11. Mean (polygon width) and one standard error (inset bars) for *S. striatinum* within four depth zones (0-3) and three regions (N, D, S) for six major surveys of Lake Michigan near the Cook Plant.

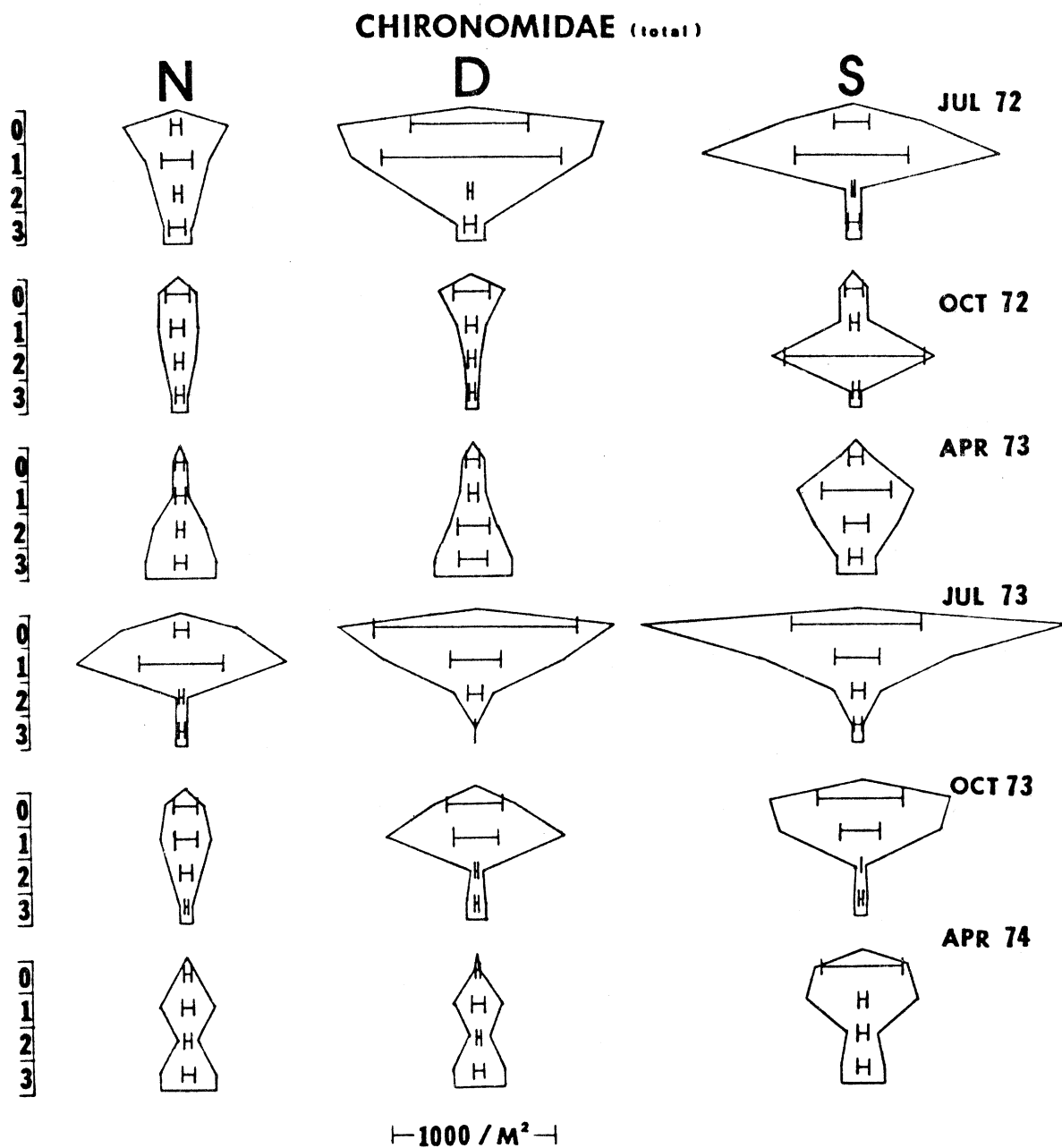


FIG. 12. Mean (polygon width) and one standard error (inset bars) for Chironomidae within four depth zones (0-3) and three regions (N, D, S) for six major surveys of Lake Michigan near the Cook Plant.

survey to survey in zone 1 of those regions. Highest estimates of tubificid density fell in July and April 1973 in the south reference region and in October 1973 in the central region (D). Standard errors were nearly as great as the means in most cases, illustrating the extremely patchy distribution of these worms in lake sediments (Mozley 1974). Numbers of tubificid worms were low in zone 0, with the exception of the north region in October 1972.

Naididae, third most numerous among oligochaete families near the Cook Plant, comprised a mixture of five common genera and numerous rarer ones (see later sections). Abundance data (Fig. 8) should be taken only as a general indication of population fluctuations, for most of these small worms are lost through our 0.5-mm sieve. Differences among regions were neither large nor consistent. The July 1973 survey yielded the highest estimates so far for this group. Relative numerical differences from year to year were greater than those for other taxa. Zones 0 and 1 characteristically had larger populations than deeper areas, particularly in summer.

Pisidium, too, comprised several species. However, none were small enough to escape through the 0.5-mm sieve. Like *Stylodrilus*, combined *Pisidium* became more abundant with increasing depth, especially in the depth range 20-30 m (Fig. 9). This abrupt increase corresponded to a shift in composition; the very abundant species in zone 3, *Pisidium conventus*, was only a minor faunal component in shallower zones (see later sections). The genus as a whole was the third- or fourth-ranked taxon in order of density on most surveys. Standard errors were inversely proportional to means, largely because of the remarkably even distribution of *P. conventus* in zone 3. *Pisidium* were rarely encountered in zone 0.

Sphaerium nitidum, the most numerous representative of the larger sphaeriid genus, typically had large standard errors associated with the mean (Fig. 10). Lack of patterns in regional or seasonal abundance may be attributable to low precision in descriptive data. The only noteworthy characteristic of this species' distribution was frequent occurrence of a maximum in zone 2, particularly in the major surveys of July and October 1973 and April 1974.

Sphaerium striatinum was considered a "major" taxon more because of its size than its abundance; with a length of over 1 cm and a height of more than 5 mm in larger specimens, it was larger than any benthic

invertebrate but rare crayfish and semi-planktonic *Mysis*. It was not abundant anywhere (Fig. 11) but tended to occur in the central region in somewhat larger numbers. As in the case of *S. nitidum*, this larger fingernail clam had broad error bars associated with zonal means.

Chironomidae, or midgefly larvae, were the only other major taxon represented consistently in most zones, regions and seasons (Fig. 12). Chironomids comprised many species, and species dominance changed from season to season. Particular assemblages of species were characteristic of zone 0 and zones 2 and 3, however. Small species and early instars of large species were sampled poorly on regular surveys, due to losses through the screen. Highest numbers occurred in July surveys as larvae of several species grew to sizes which enabled them to be retained on the 0.5-mm screen, then metamorphosed to adult midges before October surveys. Chironomids were usually more abundant in the south region, or south and central regions, than in the north region in zones 0 and 1.

Major surveys showed apparent regional differences before operation of the plant in at least two depth zones for numbers of Tubificidae and Chironomidae, which were more numerous toward the south, and *Pontoporeia*, which was more numerous to the north. Such trends are commonly interpreted to indicate greater supply of organic matter to the benthos in the area where worms and midges are stimulated (Mozley and Alley 1973; Carr and Hiltunen 1965; Howmiller and Beeton 1971). The St. Joseph River is the most obvious source of allochthonous detritus near the Cook Plant, but should affect northern parts of the survey area more than southern. Either circulation patterns or regional differences in allochthonous primary production appear to override the effects of the St. Joseph River effluent. Data for the other taxa did not follow these trends distinctly, however, either because of low sampling precision or lack of response to the causal environmental gradients. More evenly distributed taxa among regions within comparable depth zones were *Stylodrilus*, *Pisidium* and Naididae. Total numbers of zoobenthos generally failed to show north-south trends except in zone 1. There, tubificids were sufficiently numerous that they significantly affected total numbers, even when combined with other taxa which were less numerous in the south than in other regions (*Pontoporeia*).

MONTHLY VARIATIONS IN THE CENTRAL (D) REGION

Abundance estimates for major taxa in monthly, short surveys provide information supplemental to major, seasonal surveys on population fluctuations and phenomena such as reproduction and growth of *Pontoporeia affinis*. As short survey data are almost exclusively confined to the center of the survey area, only data from region D of major surveys were employed in constructing monthly graphs. Graphs presented previously (Mozley 1974) are extended here to include all 1974 data. Data from each station of the short survey design are also given in tabular form (Tables 3 through 6).

Graphs for stations falling in the central (D) region (cf. Figs. 4-12) were prepared by treating each replicate cast of the grab as a separate observation, regardless of the station at which it had been taken, so that there were 20 observations in zone D0 (stations DC-0, DC-1, NDC-.5-1, SDC-.5-1, each with 5 replicates), 3 observations in zone D1 (station DC-2 with 3 replicates), 6 observations in zone D2 (stations DC-3 and DC-4, each with 3 replicates), and 6 in zone D3 (stations DC-5 and DC-6, each with 3 replicates) for each short survey month. Means and standard errors were calculated and plotted, and means for successive months were connected. Major survey data from respective zones were calculated in the same way and also plotted on the graphs. Due to changes in the design of major surveys for July and October 1974 (Fig. 2a) no estimate was obtained for zone D3 populations. Means for June and August short surveys were simply connected. November short surveys in 1973 and 1974 were cancelled because of inclement weather.

Most extensions of data for an additional 13-month period (Figs. 13-20) produced no new features of seasonal abundance in comparison to patterns described earlier (Mozley 1974). Trends toward increased abundances of total animals (Fig. 13), *Pontoporeia* (Fig. 14, D1 and D2), Tubificidae (Fig. 16, D1-D3) and Naididae (Fig. 17, D0 and D1) ended with 1974 declines of populations to 1971 or 1972 levels. Chironomidae, however, increased or maintained peak abundances of the previous year (Fig. 20, D0-D2). Corresponding year-to-year fluctuations in several of the most abundant taxa suggest that some environmental factor operated on a wide variety of zoobenthos similarly; primary production could be one such factor. Continued high numbers of Chironomidae in 1974 may have been a response to reduced competition for food (? recently sedimented detritus) by

TABLE 3. Station means and standard errors for macroscopically identifiable animals (major taxa) in the May 1974 short survey of benthos. Units are numbers/m².

TAXON	DC-0*	DC-1*	NDC-5-1*	SDC-5-1*	NDC-7-1*	SDC-7-1*	DC-2**
<i>Pontoporeia</i>	0	13.6 ± 13.6	8.16 ± 5.02	12.2 ± 12.2	0	16.3 ± 7.66	424 ± 245
Tubificidae	0	27.2 ± 13.5	0	0	0	8.16 ± 5.02	2050 ± 2838
Naididae	0	0	0	0	0	0	0
<i>Stylodrilus</i>	0	0	16.3 ± 7.66	0	0	4.08 ± 4.08	80.8 ± 53.5
<i>Sph. nitidum</i>	0	0	0	4.08 ± 4.08	0	0	0
<i>Sph. striatulum</i>	0	0	0	0	0	0	20.2 ± 20.2
<i>Pisidium</i> spp.	5.10 ± 5.10	0	24.5 ± 7.66	0	8.16 ± 8.16	16.3 ± 7.66	828 ± 650
Chironomidae	0	40.8 ± 20.4	24.5 ± 16.3	49.0 ± 30.0	49.0 ± 34.5	57.1 ± 19.8	242 ± 92.7
Hirudinea	0	0	12.2 ± 8.12	8.16 ± 5.02	0	4.08 ± 4.08	222 ± 193
Operculata	0	0	0	0	0	0	80.8 ± 40.2
Pulmonata	0	0	0	0	0	0	20.2 ± 20.2
Other	0	0	4.08 ± 4.08	0	0	0	20.2 ± 20.2
Total animals	5.10 ± 5.10	81.6 ± 20.4	89.7 ± 22.9	73.4 ± 49.4	57.2 ± 42.5	106 ± 37.3	4988 ± 3851

TAXON	DC-3**	DC-4**	DC-5**	DC-6**	NDC-7-5**	SDC-7-5**
<i>Pontoporeia</i>	747 ± 687	768 ± 176	6626 ± 626	6545 ± 789	5151 ± 648	2565 ± 72.8
Tubificidae	2969 ± 2144	7171 ± 6688	1818 ± 827	5050 ± 790	3212 ± 1154	4585 ± 2229
Naididae	0	0	0	0	0	0
<i>Stylodrilus</i>	242 ± 242	242 ± 105	4989 ± 934	2949 ± 428	3192 ± 1032	2384 ± 735
<i>Sph. nitidum</i>	283 ± 283	162 ± 72.8	20.2 ± 20.2	0	242 ± 60.5	202 ± 72.8
<i>Sph. striatulum</i>	60.6 ± 60.6	0	0	0	0	0
<i>Pisidium</i> spp.	4080 ± 3838	1454 ± 633	2990 ± 1188	5353 ± 225	1515 ± 420	2101 ± 417
Chironomidae	707 ± 281	242 ± 70.0	101 ± 40.2	101 ± 20.3	283 ± 40.2	182 ± 92.7
Hirudinea	303 ± 213	0	0	20.2 ± 20.2	40.4 ± 40.4	40.4 ± 20.3
Operculata	121 ± 121	80.8 ± 80.8	0	20.2 ± 20.2	283 ± 53.5	0
Pulmonata	40.4 ± 40.4	0	0	0	0	0
Other	0	0	0	0	0	0
Total animals	9553 ± 7869	10120 ± 7430	16544 ± 1840	20038 ± 2076	13918 ± 965	12059 ± 2581

* t.05 (4 d.f.) = 2.8 Compare footnote to Table 1.

** t.05 (2 d.f.) = 4.3

TABLE 4. Station means and standard errors for macroscopically identifiable animals (major taxa) in the June 1974 short survey of benthos. Units are numbers/m².

TAXON	DC-0*	DC-1*	NDC-5-1*	SDC-5-1*	NDC-7-1*	SDC-7-1*	DC-2**
<i>Pontoporeia</i>	0	16.3 ± 7.66	44.9 ± 21.8	24.5 ± 15.0	0	36.7 ± 13.5	2323 ± 112
<i>Tubificidae</i>	0	4.08 ± 4.08	16.3 ± 7.66	8.16 ± 5.02	20.4 ± 20.4	4.08 ± 4.08	2303 ± 278
<i>Naididae</i>	0	53.0 ± 28.6	8.16 ± 5.02	0	0	4.08 ± 4.08	20.2 ± 20.2
<i>Stylodrilus</i>	0	4.08 ± 4.08	16.3 ± 11.9	4.08 ± 4.08	0	4.08 ± 4.08	0
<i>Sph. nitidum</i>	0	0	0	0	0	0	40.4 ± 40.4
<i>Sph. striatum</i>	0	0	0	0	0	0	60.6 ± 35.0
<i>Platidium</i> spp.	0	0	12.2 ± 5.02	0	4.08 ± 4.08	16.3 ± 11.9	970 ± 264
<i>Chironomidae</i>	61.2 ± 28.1	690 ± 100	763 ± 171	506 ± 99.0	208 ± 63.7	481 ± 81.0	182 ± 70.0
<i>Hirudinea</i>	0	4.08 ± 4.08	0	0	8.16 ± 5.02	0	0
<i>Operculata</i>	0	0	0	0	0	4.08 ± 4.08	283 ± 162
<i>Pulmonata</i>	0	0	0	0	0	0	20.2 ± 20.2
Other	0	4.08 ± 4.08	20.4 ± 9.12	4.08 ± 4.08	0	8.16 ± 5.02	242 ± 126
Total animals	61.2 ± 28.1	776 ± 127	881 ± 195	547 ± 101	241 ± 68.1	558 ± 99.4	6444 ± 435

TAXON	DC-3**	DC-4**	DC-5**	DC-6**	NDC-7-5**	SDC-7-5**
<i>Pontoporeia</i>	1050 ± 40.2	4565 ± 1010	6868 ± 980	5939 ± 473	4727 ± 681	5111 ± 830
<i>Tubificidae</i>	2343 ± 688	1212 ± 334	2040 ± 924	3474 ± 598	5090 ± 735	1495 ± 123
<i>Naididae</i>	0	20.2 ± 20.2	0	0	0	60.6 ± 60.6
<i>Stylodrilus</i>	182 ± 60.5	1374 ± 371	6828 ± 691	3596 ± 435	4202 ± 592	2990 ± 717
<i>Sph. nitidum</i>	20.2 ± 20.2	263 ± 123	60.6 ± 0	0	1677 ± 1404	20.2 ± 20.2
<i>Sph. striatum</i>	20.2 ± 20.2	0	0	0	0	80.8 ± 53.5
<i>Platidium</i> spp.	364 ± 195	263 ± 101	7999 ± 3646	3798 ± 316	2202 ± 616	707 ± 246
<i>Chironomidae</i>	182 ± 35.0	40.4 ± 20.3	121 ± 92.7	141 ± 40.2	121 ± 35.0	60.6 ± 35.0
<i>Hirudinea</i>	0	0	0	20.2 ± 20.2	40.4 ± 40.4	0
<i>Operculata</i>	0	40.4 ± 40.4	20.2 ± 20.2	0	424 ± 218	20.2 ± 20.2
<i>Pulmonata</i>	0	0	0	0	0	0
Other	303 ± 303	101 ± 20.3	20.2 ± 20.2	0	0	80.8 ± 40.2
Total animals	4464 ± 1028	7879 ± 992	23957 ± 4384	16968 ± 1165	18483 ± 2139	10626 ± 1469

* t.05 (4 d.f.) = 2.8 Compare footnote to Table 1.

** t.05 (2 d.f.) = 4.3

TABLE 5. Station means and standard errors for macroscopically identifiable animals (major taxa) in the August 1974 short survey of benthos. Units are numbers/m².

TAXON	DC-0*	DC-1*	NDC-.5-1 *	SDC-.5-1 *	NDC-7-1 *	SDC-7-1 *	DC-2 **
<i>Pontoporeia</i>	0	28.6 ± 15.2	0	0	0	28.6 ± 10.4	1232 ± 53.5
Tubificidae	0	65.3 ± 21.8	44.9 ± 17.5	53.0 ± 43.5	49.0 ± 21.0	0	1192 ± 378
Maillidae	16.3 ± 10.0	12.2 ± 5.02	40.8 ± 31.6	175 ± 59.0	171 ± 43.5	81.6 ± 28.1	182 ± 126
<i>Stylodrilus</i>	0	0	4.08 ± 4.08	0	16.3 ± 11.9	0	20.2 ± 20.2
<i>Sph. nitidum</i>	0	0	0	0	4.08 ± 4.08	0	60.6 ± 35.0
<i>Sph. striatum</i>	0	0	4.08 ± 4.08	0	0	0	162 ± 20.3
<i>Pisidium</i> spp.	0	4.08 ± 4.08	4.08 ± 4.08	0	16.3 ± 7.66	16.3 ± 11.9	1899 ± 101
Chironomidae	343 ± 105	726 ± 213	1032 ± 107	2224 ± 351	1024 ± 128	449 ± 92.8	485 ± 105
Hirudinea	0	8.16 ± 5.02	8.16 ± 8.16	0	4.08 ± 4.08	0	121 ± 35.0
Operculata	0	0	0	0	0	0	141 ± 88.2
Pulmonata	0	0	4.08 ± 4.08	0	0	0	0
Other	0	0	16.3 ± 7.66	8.16 ± 8.16	0	0	20.2 ± 20.2
Total animals	359 ± 101	844 ± 225	1158 ± 115	2460 ± 426	1285 ± 159	576 ± 125	5515 ± 424

TAXON	DC-3 **	DC-4 **	DC-5 **	DC-6 **	NDC-7-5 **	SDC-7-5 **
<i>Pontoporeia</i>	949 ± 107	2848 ± 273	5919 ± 1860	5979 ± 432	2747 ± 214	1596 ± 332
Tubificidae	1980 ± 1434	1858 ± 498	465 ± 133	3818 ± 538	2949 ± 986	667 ± 242
Maillidae	323 ± 72.8	60.6 ± 35.0	0	0	0	0
<i>Stylodrilus</i>	101 ± 72.8	1697 ± 370	2929 ± 768	2666 ± 619	1879 ± 299	444 ± 101
<i>Sph. nitidum</i>	0	80.8 ± 20.3	80.8 ± 80.8	40.4 ± 20.3	586 ± 283	222 ± 72.8
<i>Sph. striatum</i>	20.2 ± 20.2	0	20.2 ± 20.2	0	0	0
<i>Pisidium</i> spp.	667 ± 273	646 ± 141	1252 ± 496	4424 ± 242	1394 ± 576	1778 ± 774
Chironomidae	909 ± 210	646 ± 193	202 ± 80.8	40.4 ± 40.4	162 ± 40.2	80.8 ± 53.5
Hirudinea	0	0	0	0	0	0
Operculata	20.2 ± 20.2	162 ± 20.3	20.2 ± 20.2	0	101 ± 20.3	60.6 ± 35.0
Pulmonata	20.2 ± 20.2	20.2 ± 20.2	20.2 ± 20.2	0	0	0
Other	0	20.2 ± 20.2	0	0	0	20.2 ± 20.2
Total animals	4990 ± 1931	8039 ± 1065	10908 ± 3075	16968 ± 1043	9818 ± 121	4869 ± 1374

* t.05 (4 d.f.) = 2.8 Compare footnote to Table 1.

** t.05 (2 d.f.) = 4.3

TABLE 6. Station means and standard errors for macroscopically identifiable animals (major taxa) in the September 1974 short survey of benthos. Units are numbers/m².

TAXON	DC-0 *	DC-1 *	NDC-5-1 *	SDC-5-1 *	NDC-7-1 *	SDC-7-1 *	DC-2 **
<i>Pontoporeia</i>	0	no	0	36.7 ± 11.9	24.5 ± 11.9	16.3 ± 11.9	687 ± 214
Tubificidae	0	sample	16.3 ± 11.9	734 ± 248	49.0 ± 23.8	44.9 ± 11.9	1677 ± 626
Maididae	0	taken	159 ± 42.0	388 ± 143	208 ± 61.7	97.9 ± 31.8	525 ± 146
<i>Stylodrilus</i>	0	substrate	4.08 ± 4.08	0	16.3 ± 11.9	16.3 ± 7.66	20.2 ± 20.2
<i>Sph. nitidum</i>	0	too	0	0	0	0	20.2 ± 20.2
<i>Sph. striatinum</i>	0	hard	0	0	0	0	80.8 ± 40.2
<i>Pleidium</i> spp.	0		8.16 ± 5.02	8.16 ± 8.16	8.16 ± 5.02	16.3 ± 4.11	1778 ± 622
Chironomidae	93.8 ± 21.0		1228 ± 114	3505 ± 308	1204 ± 100	592 ± 59.5	343 ± 225
Hirudinea	0		0	4.08 ± 4.08	0	0	0
Operculata	0		4.08 ± 4.08	16.3 ± 11.9	0	8.16 ± 5.02	121 ± 70.0
Pulmonata	0		4.08 ± 4.08	0	0	0	0
Other	0		44.9 ± 13.5	24.5 ± 15.0	12.2 ± 8.12	24.5 ± 10.0	60.6 ± 60.6
Total animals	93.8 ± 21.0		1469 ± 152	4717 ± 497	1522 ± 162	816 ± 86.3	5312 ± 1468

TAXON	DC-3 **	DC-4 **	DC-5 **	DC-6 **	NDC-7-5 **	SDC-7-5 **
<i>Pontoporeia</i>	727 ± 264	1838 ± 630	7272 ± 1137	6464 ± 495	2363 ± 490	2424 ± 702
Tubificidae	17816 ± 17033	5454 ± 2514	808 ± 225	4222 ± 1068	5696 ± 3115	3212 ± 723
Maididae	525 ± 336	343 ± 285	0	0	0	20.2 ± 20.2
<i>Stylodrilus</i>	141 ± 72.8	3414 ± 2264	5333 ± 1776	3171 ± 141	2141 ± 577	2606 ± 697
<i>Sph. nitidum</i>	60.6 ± 60.6	263 ± 233	0	0	263 ± 133	141 ± 53.5
<i>Sph. striatinum</i>	40.4 ± 40.4	0	0	0	20.2 ± 20.2	0
<i>Pleidium</i> spp.	424 ± 334	1515 ± 337	3131 ± 1051	4666 ± 1738	1980 ± 336	1515 ± 121
Chironomidae	2182 ± 1789	646 ± 20.3	101 ± 40.2	60.6 ± 0	162 ± 53.5	121 ± 0
Hirudinea	424 ± 424	0	0	0	0	0
Operculata	40.4 ± 20.3	263 ± 112	20.2 ± 20.2	0	343 ± 107	40.4 ± 40.4
Pulmonata	40.4 ± 20.3	101 ± 72.8	0	20.2 ± 20.2	0	0
Other	0	0	0	0	20.2 ± 20.2	40.4 ± 40.4
Total animals	22421 ± 19831	13837 ± 2836	16665 ± 4142	18604 ± 759	12988 ± 3750	10120 ± 1656

* t.05 (4 d.f.) = 2.8 Compare footnote to Table 1.

** t.05 (2 d.f.) = 4.3

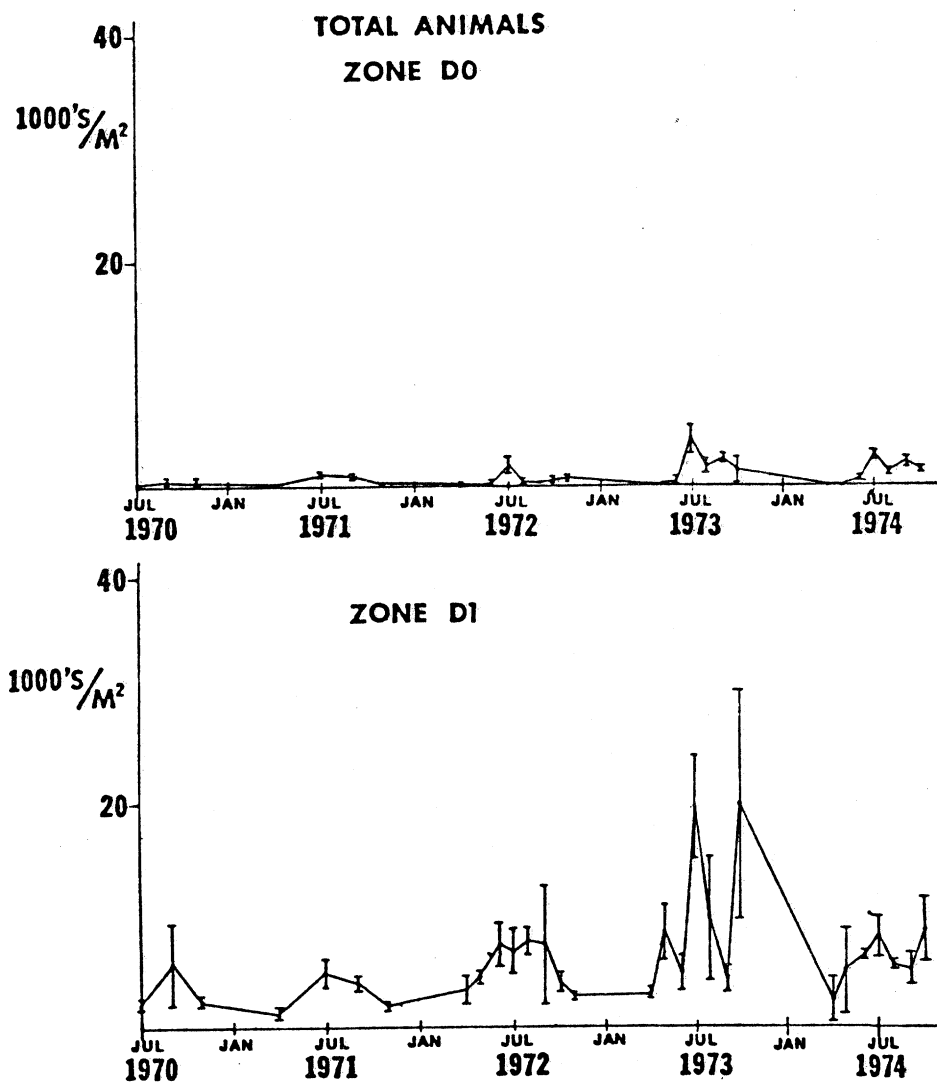


FIG. 13. Means and standard errors (brackets) by benthic depth zone (D0-D3) for total animals at all stations falling within the D region over all surveys from July 1970 through October 1974. See text for limits of depth zones.

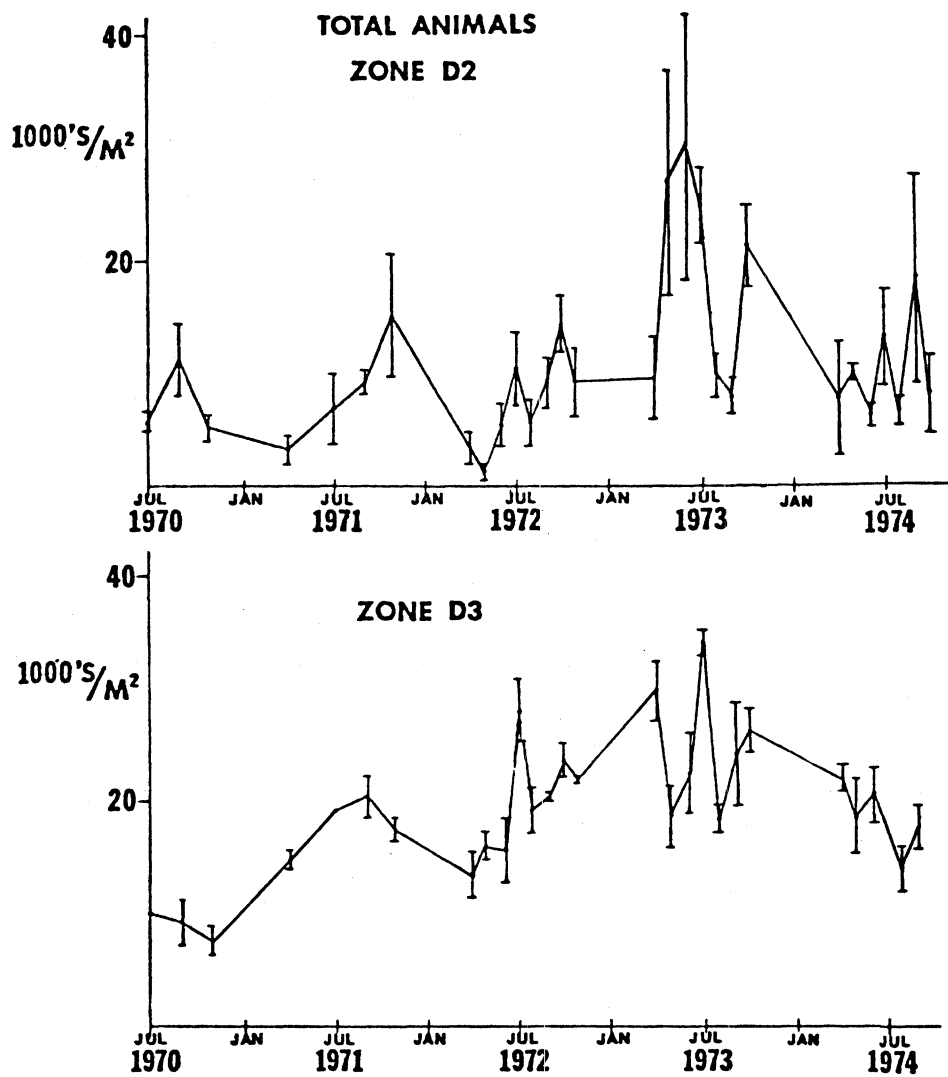


FIG. 13 continued.

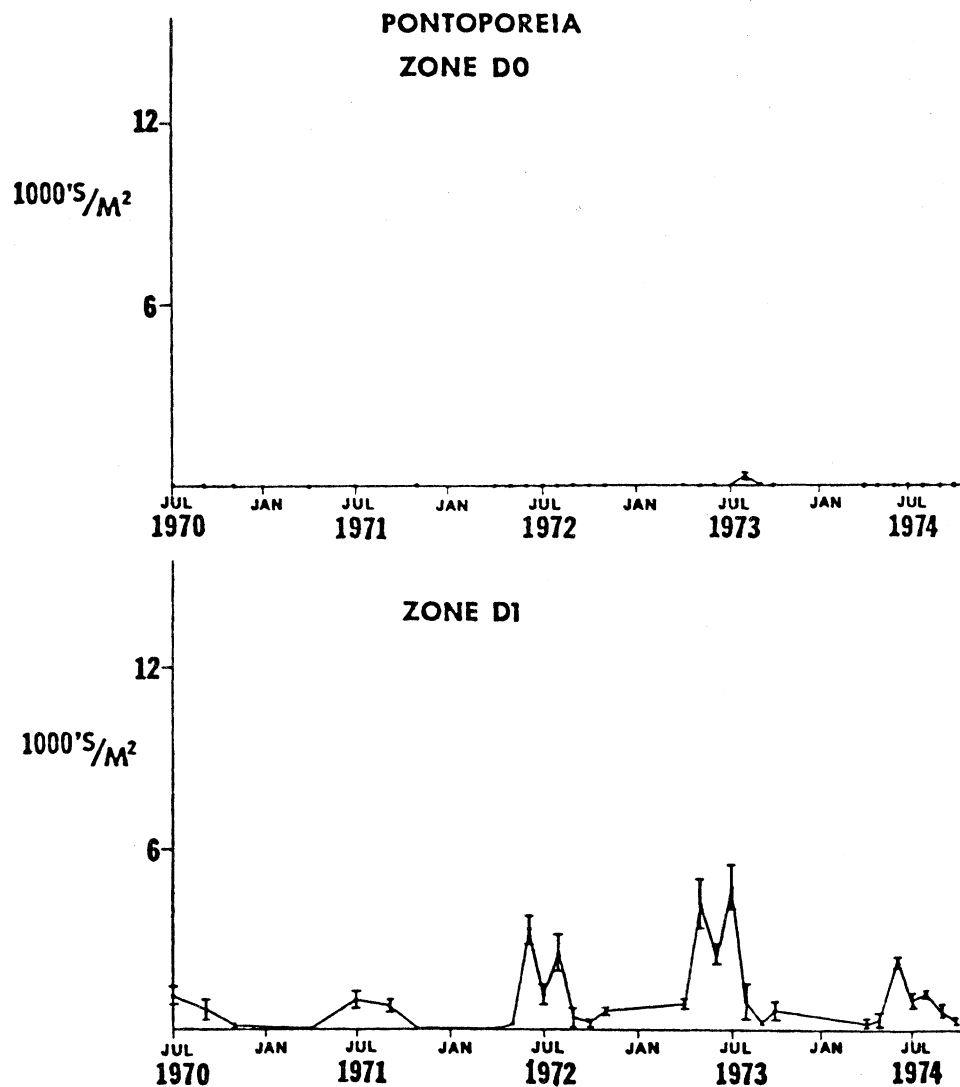


FIG. 14. Means and standard errors (brackets) by benthic depth zone (D0-D3) for *Pontoporeia affinis* at all stations falling within the D region over all surveys from July 1970 through October 1974. See text for limits of depth zones.

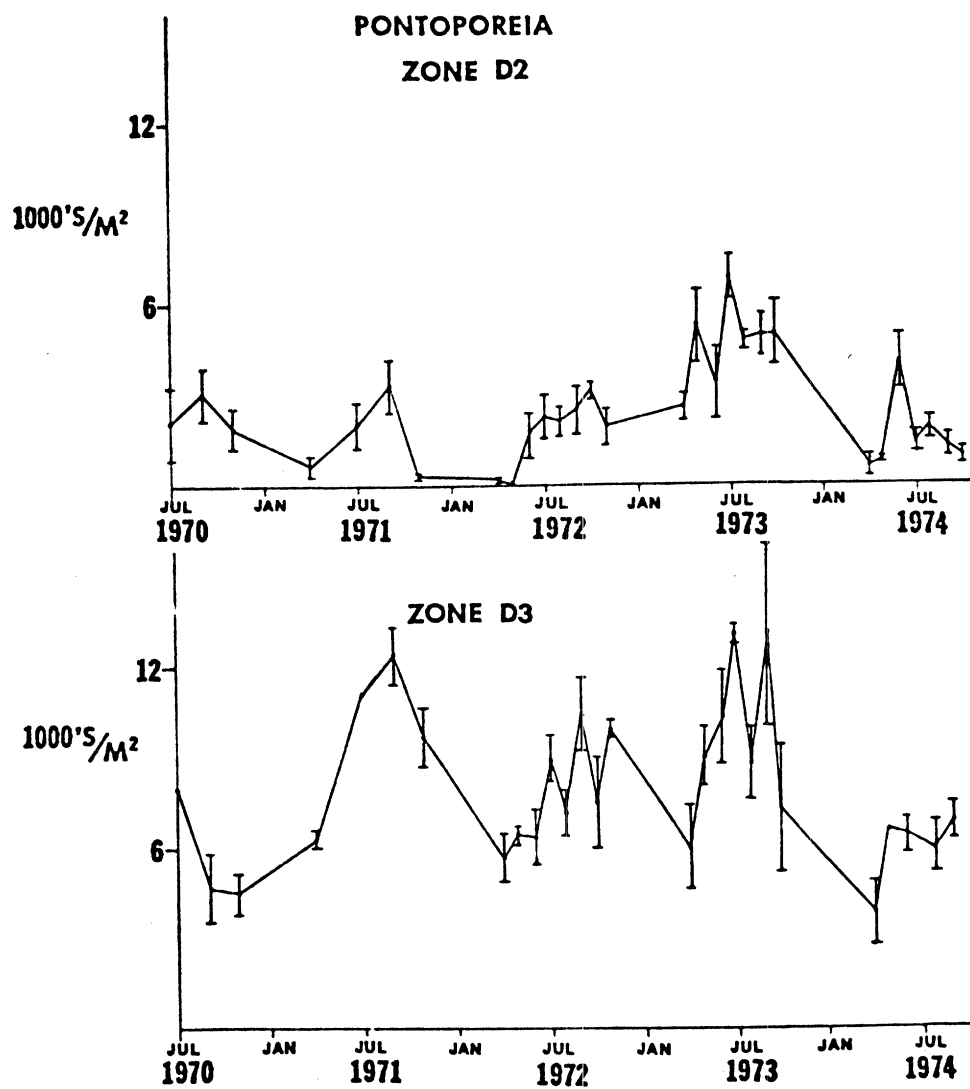


FIG. 14 continued.

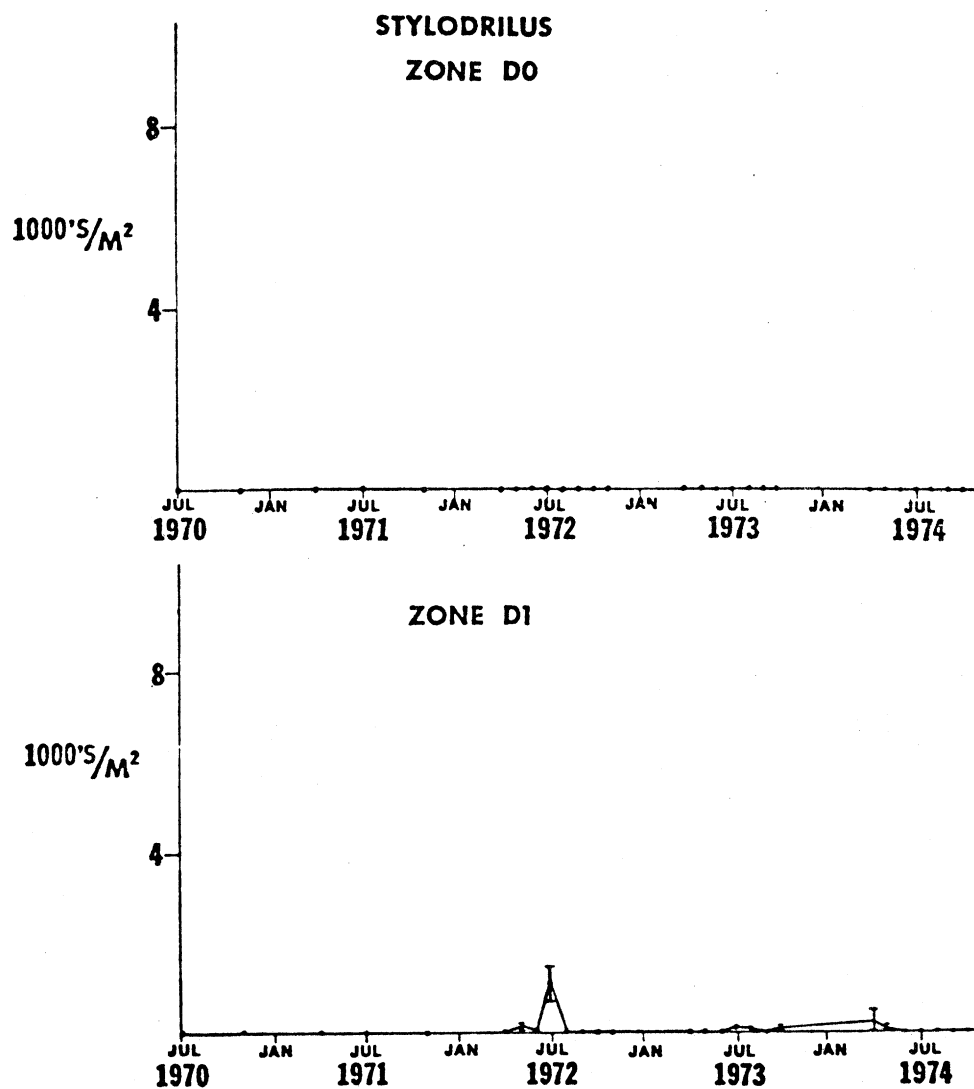


FIG. 15. Means and standard errors (brackets) by benthic depth zone for *Stylodrilus heringianus* at all stations falling within the D region over all surveys from July 1970 through October 1974. See text for limits of depth zones.

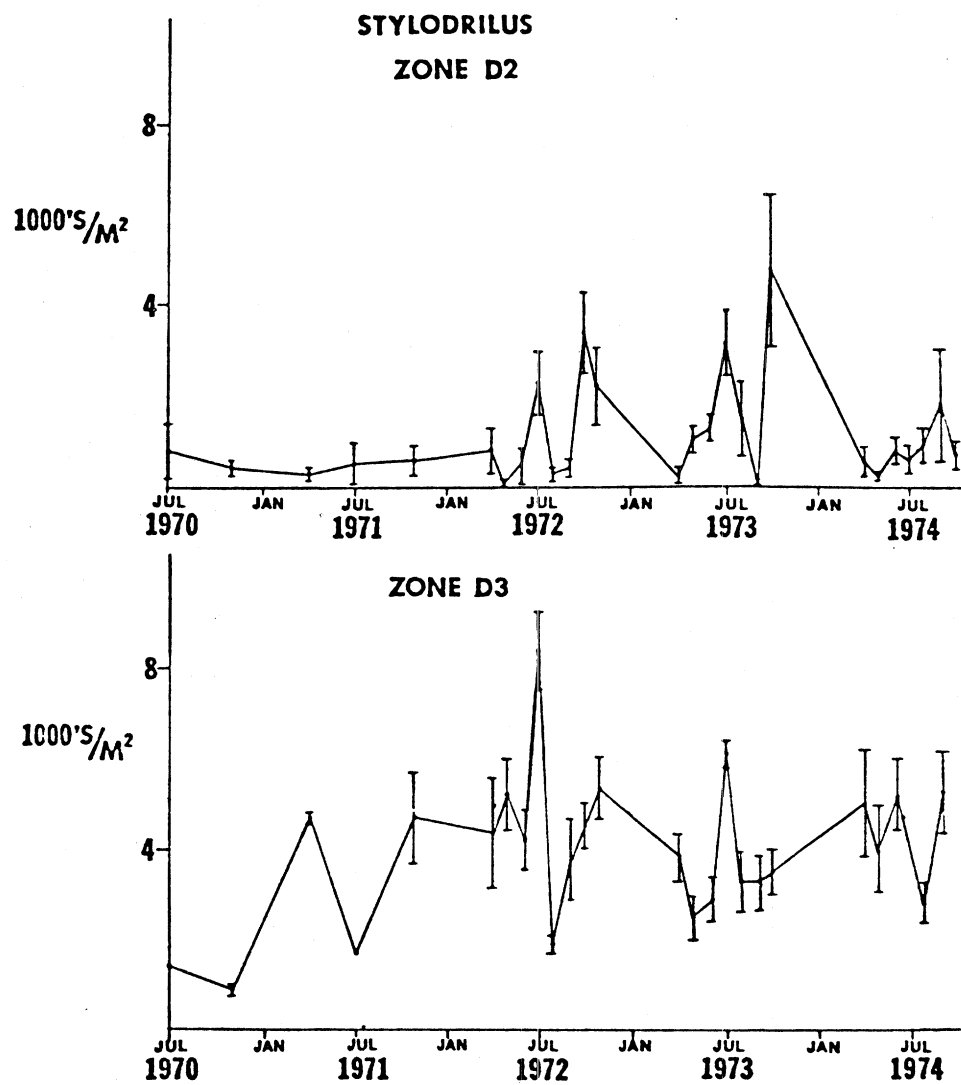


FIG. 15 continued.

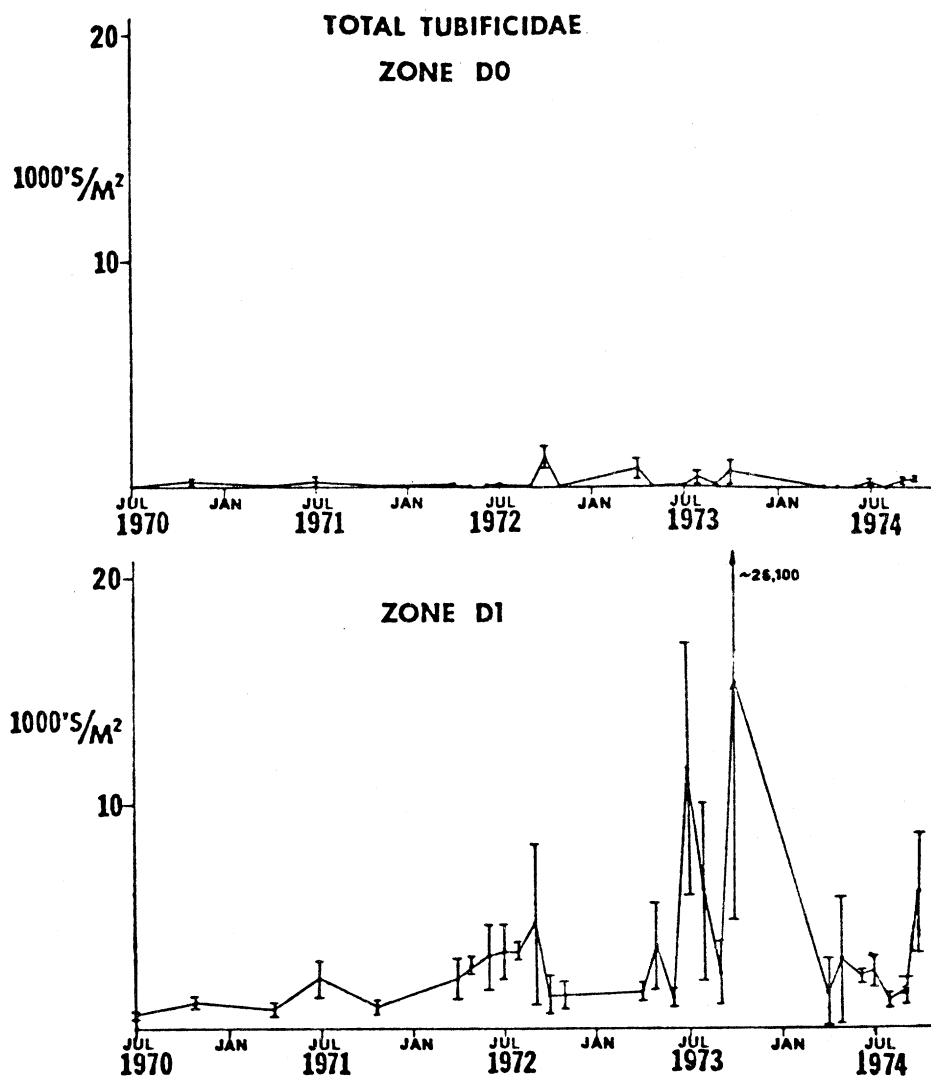


FIG. 16. Means and standard errors (brackets) by benthic depth zone (D0-D3) for total Tubificidae at all stations falling within the D region over all surveys from July 1970 through October 1974. See text for limits of depth zones.

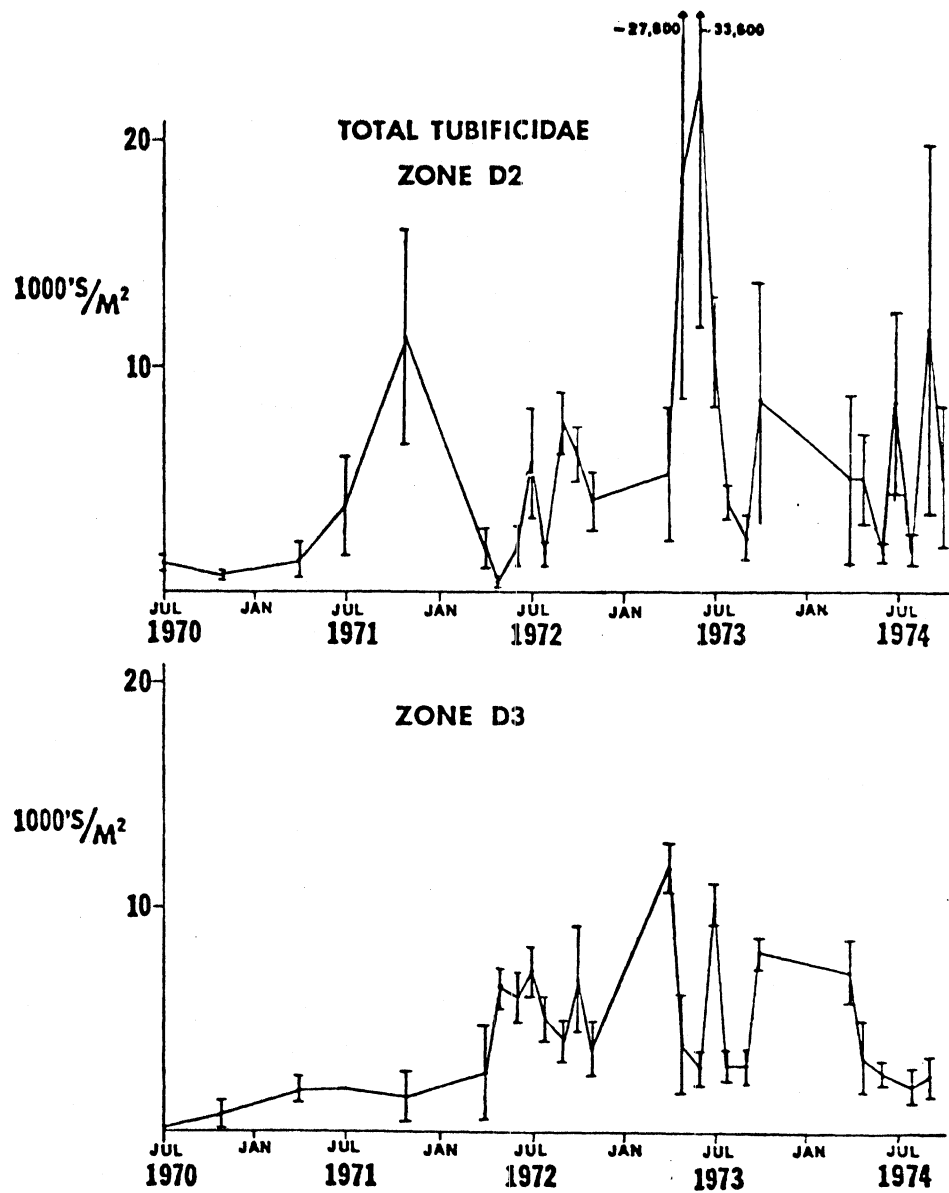


FIG. 16 continued.

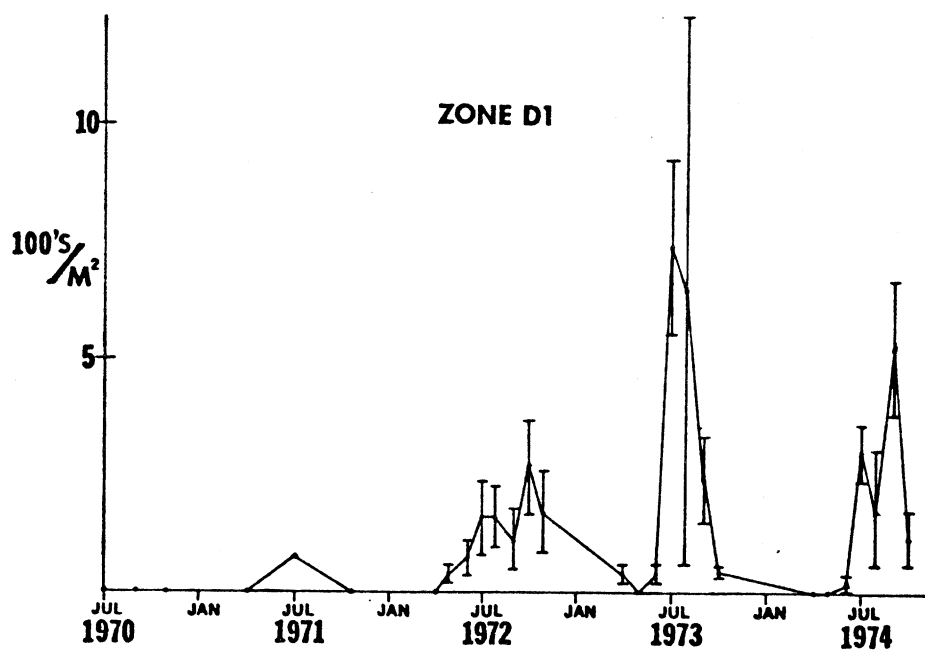
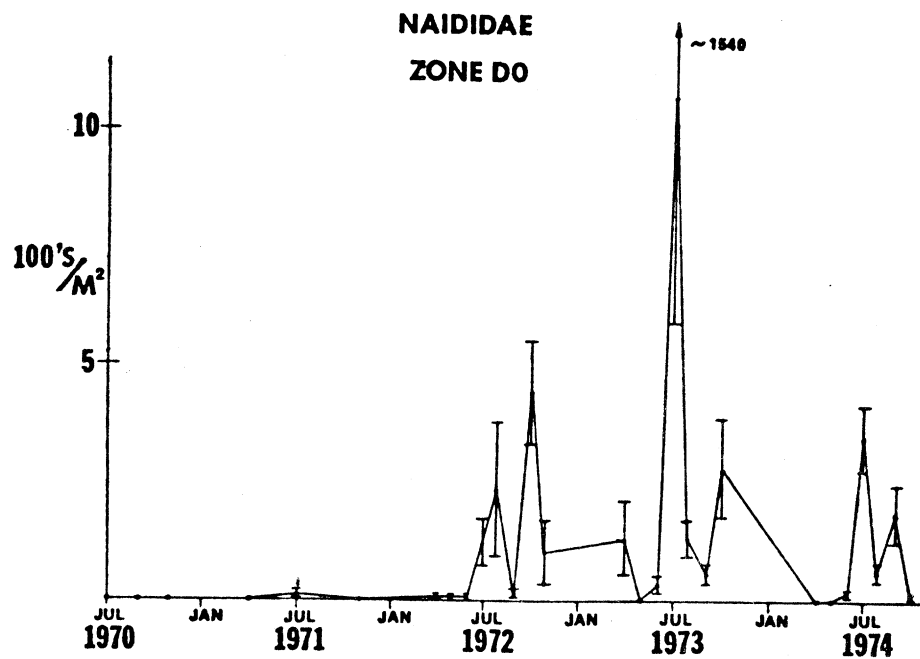


FIG. 17. Means and standard errors (brackets) by benthic depth zone (D0-D3) for total Naididae at all stations falling within the D region over all surveys from July 1970 through October 1974. See text for limits of depth zones.

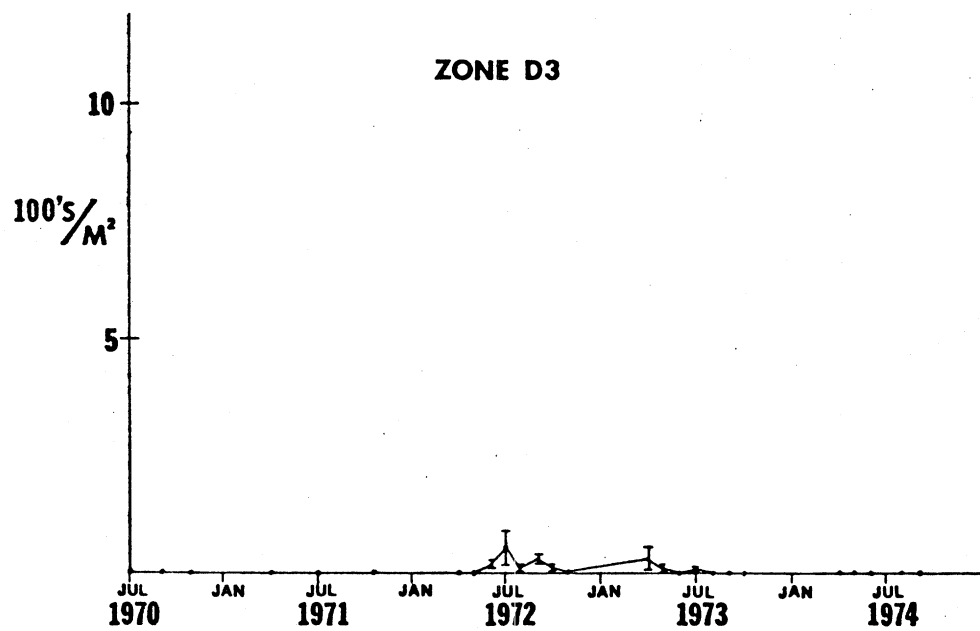
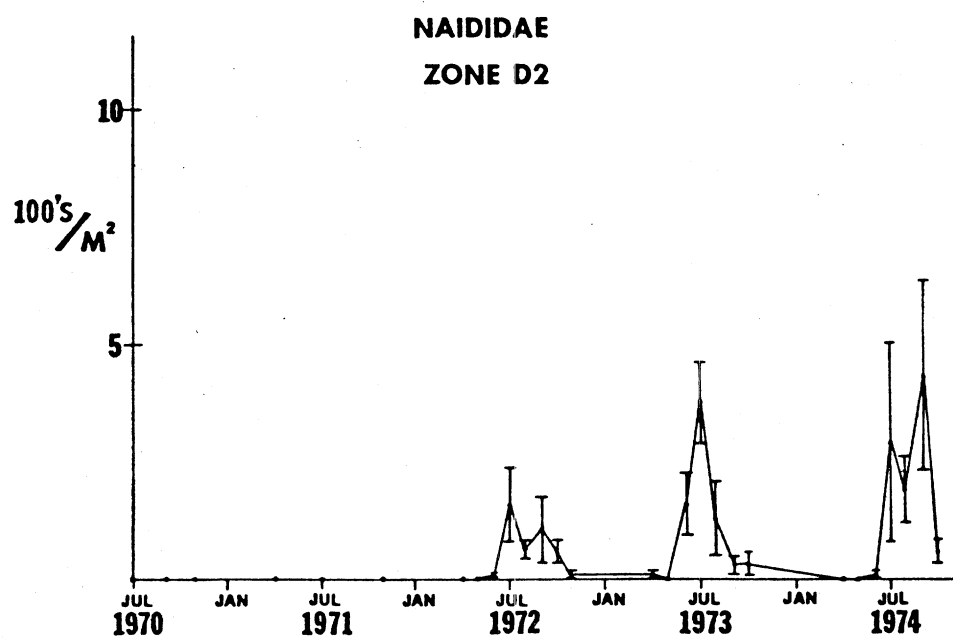


FIG. 17 continued.

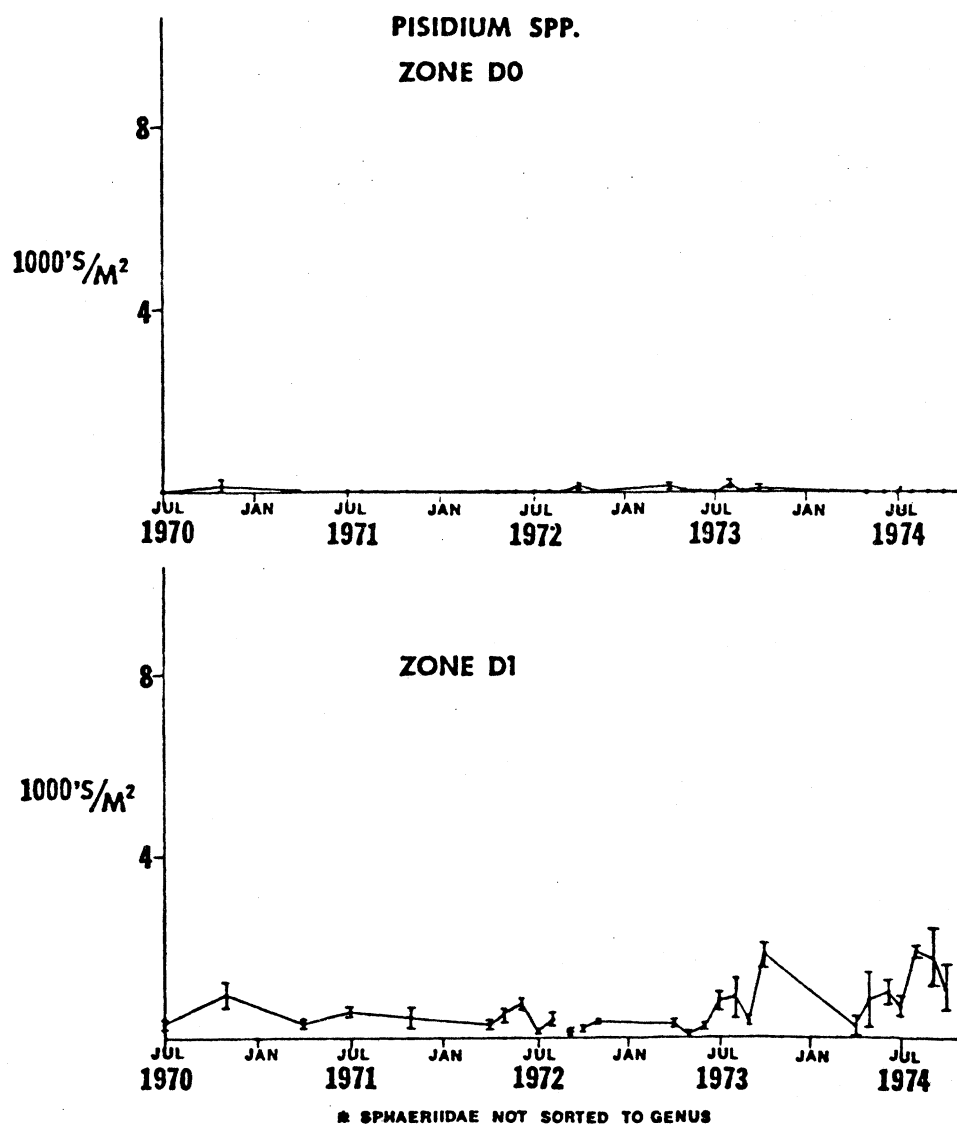


FIG. 18. Means and standard errors (brackets) by benthic depth zone (D0-D3) for total *Pisidium* at all stations falling within the D region over all surveys from July 1970 through October 1974. See text for limits of depth zones.

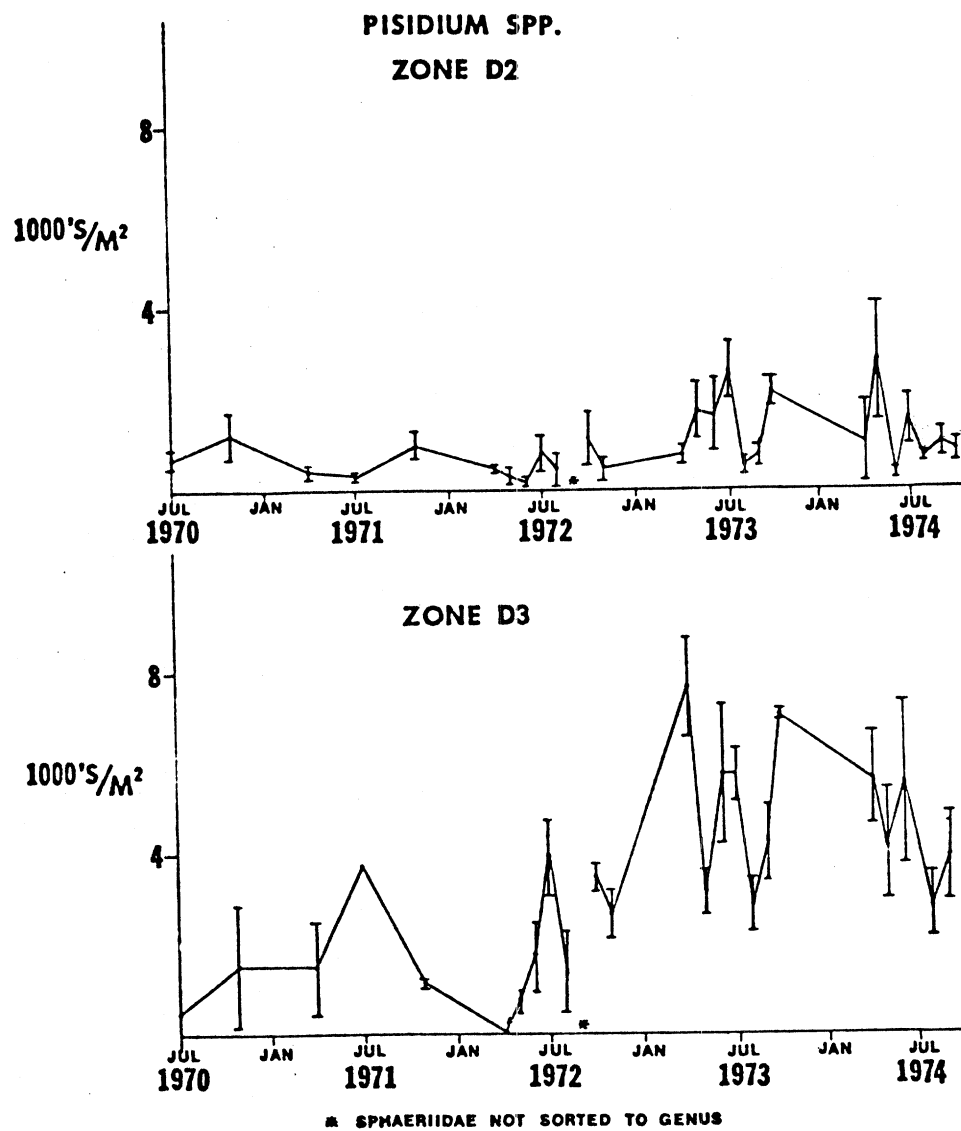


FIG. 18 continued.

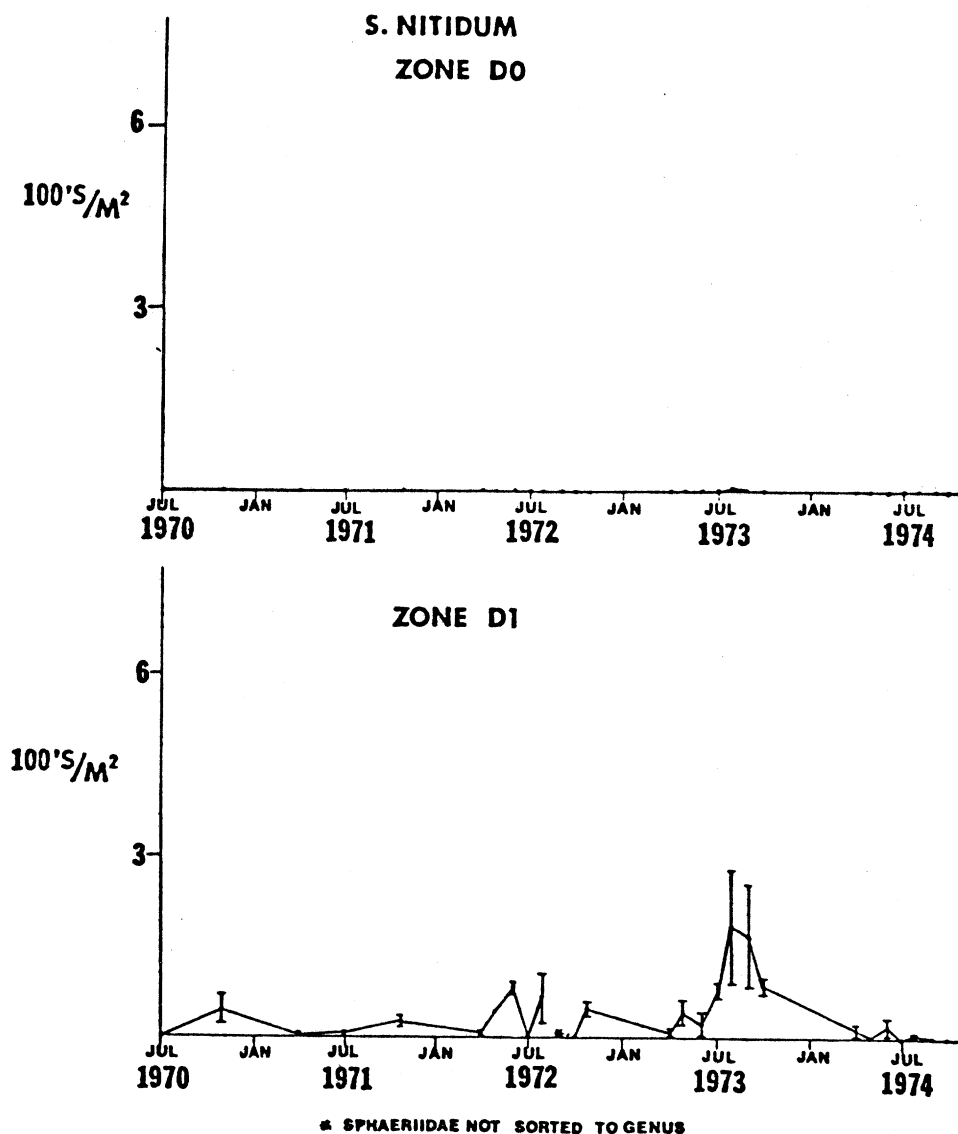


FIG. 19. Means and standard errors (brackets) by benthic depth zone (D0-D3) for *Sphaerium nitidum* at all stations falling within the D region over all surveys from July 1970 through October 1974. See text for limits of depth zones.

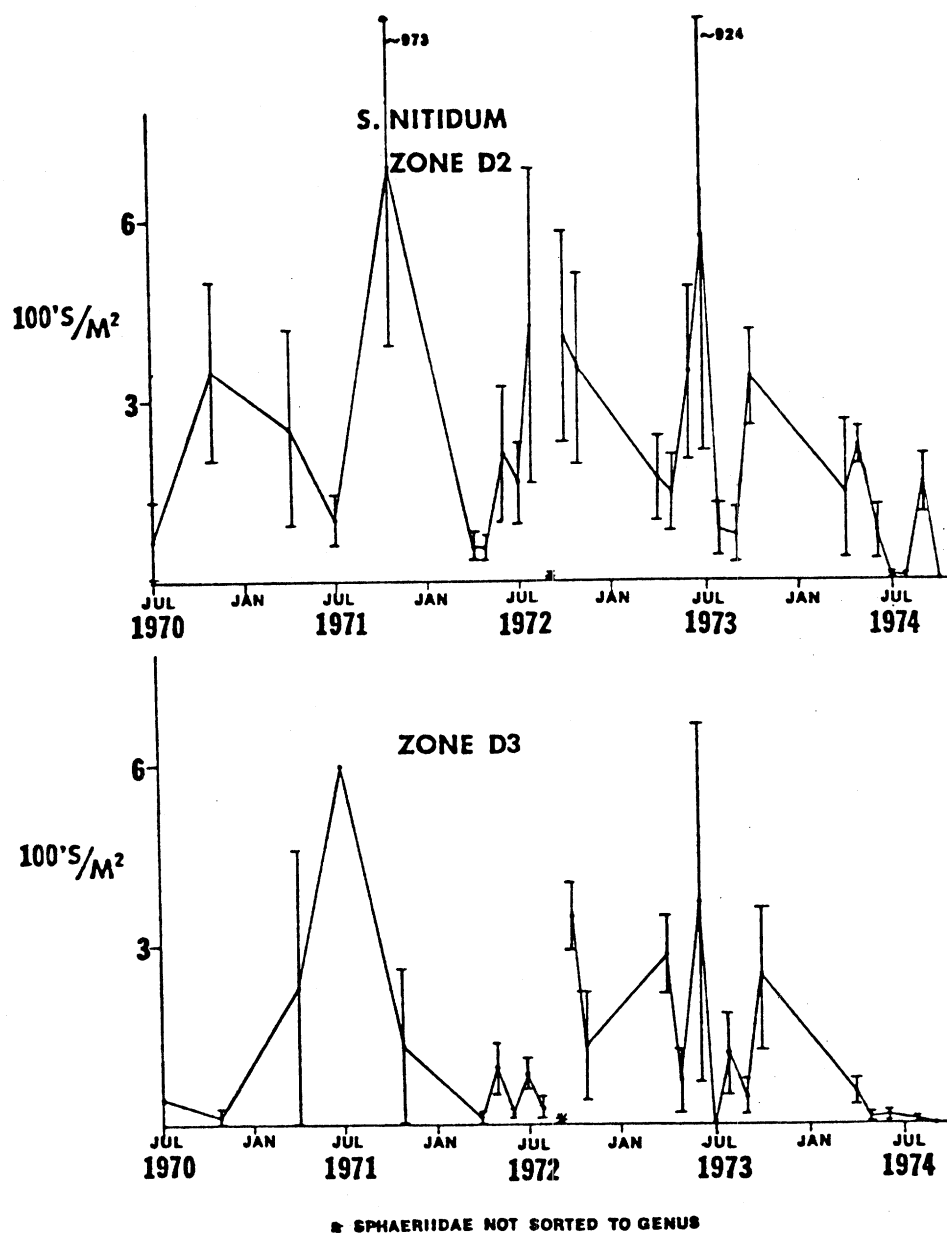


FIG. 19 continued.

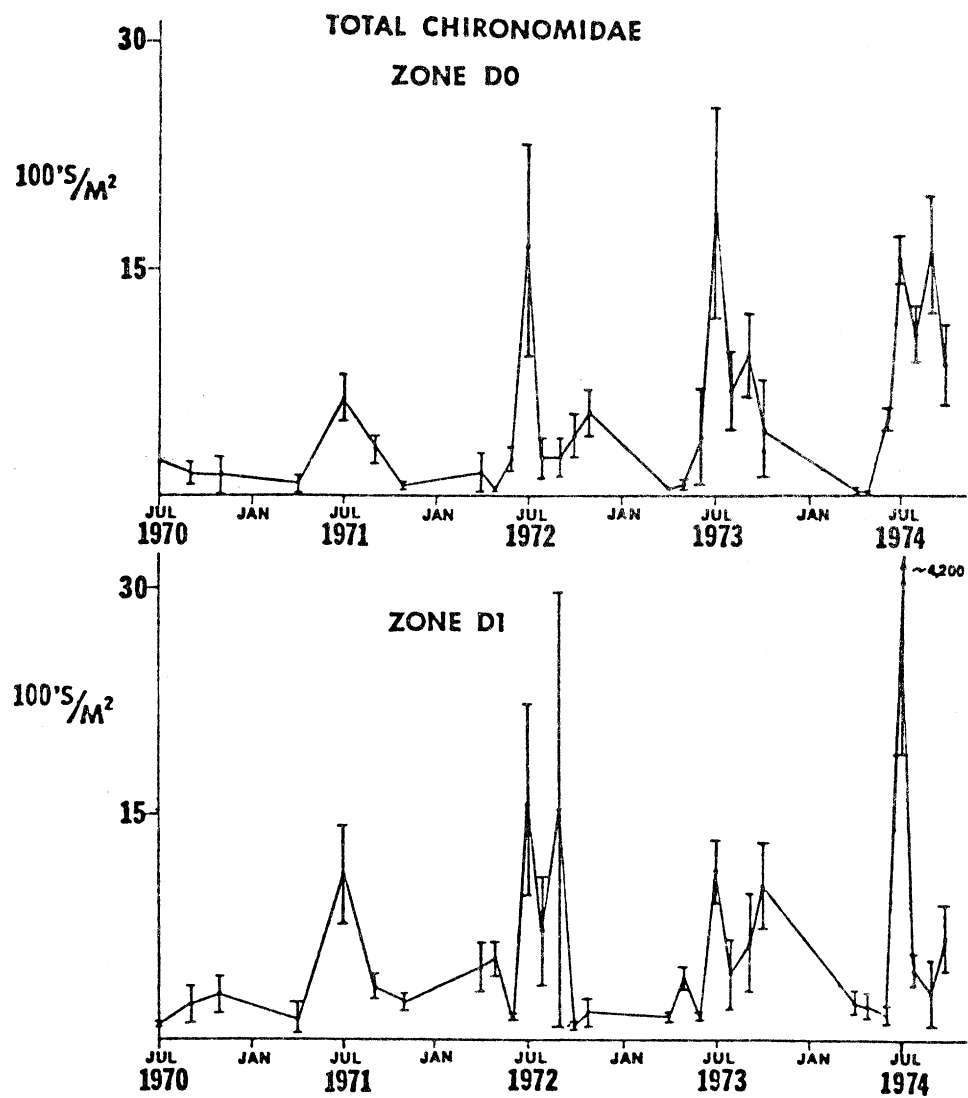


FIG. 20. Means and standard errors (brackets) by benthic depth zone (D0-D3) for total Chironomidae at all stations falling within the D region over all surveys from July 1970 through October 1974. See text for limits of depths zones.

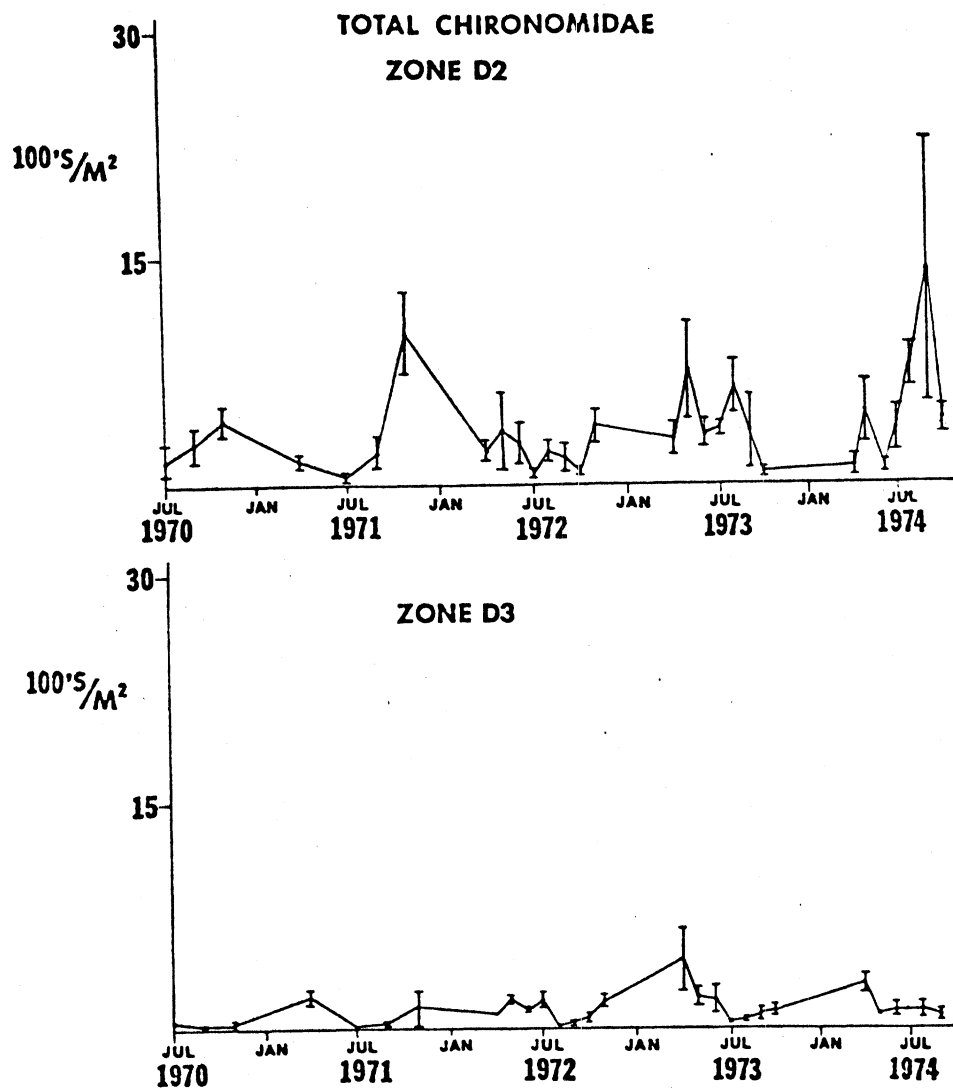


FIG. 20 continued.

Pontoporeia populations. This necessitates the hypothesis that *Pontoporeia* was diminished by factors other than the supply of food, such as predation.

SEASONAL CHANGES IN *PONTOPOREIA AFFINIS* POPULATIONS

Size and reproductive-state classes of *Pontoporeia* in 1973-74 again conformed to the seasonal pattern of 1970-1972 (Figs. 21 and 22; April-August data for 1973 have been repeated to give seasonal perspective). Depth zone 0 samples had too few *Pontoporeia* for accurate determination of population age distribution. Release of young *Pontoporeia* from brood chambers of females had begun by the April 20 survey in 1974, but unlike previous years, 1974 April samples contained both gravid and spent females as well as young in zone 1. This is taken to mean that release had just begun and young had not yet moved out of range of the grab sampler.

Summed mean daily temperatures for 1974 initiated on January 1 and converted to degrees Celsius at the St. Joseph city water intake (12 m deep) reached 316 degree-days by April 20, somewhat below the minimum of approximately 350 previously estimated to be required for release of young (Mozley 1974). The 1974 sum which accumulated before young were released was only 16C higher than the 1972 sum before the May survey, in which no newly released young were found. Based on the new estimate of the minimum sum, 310C, the hypothetical date on which young could be released if females were continuously exposed to a temperature of 4C by the sinking plume is advanced to March 19 or 20. Assumptions involved in this day-degree estimation are that the cumulative temperature beginning on January 1 of a given year is virtually the sole determining factor for the rate at which embryos in the marsupium develop, that developmental rate is proportional to temperature, and that the absence of young from survey samples means that they have not yet been released. A case in which development was not linearly proportional to temperature (in degrees Celsius) is cited by Hoglund and Spigarelli (1972). Moreover, young may move above bottom and avoid the grab sampler for a period before they assume a benthic existence, causing errors in determination of the date of release.

Pontoporeia reached the highest densities observed near the Cook Plant in zones D1 and D2 in 1973. That year was warmer in winter and early spring than 1972, and there seemed to be some connection between early release of young and large populations (Mozley 1974). Release was almost as early in

BENTHIC
ZONE

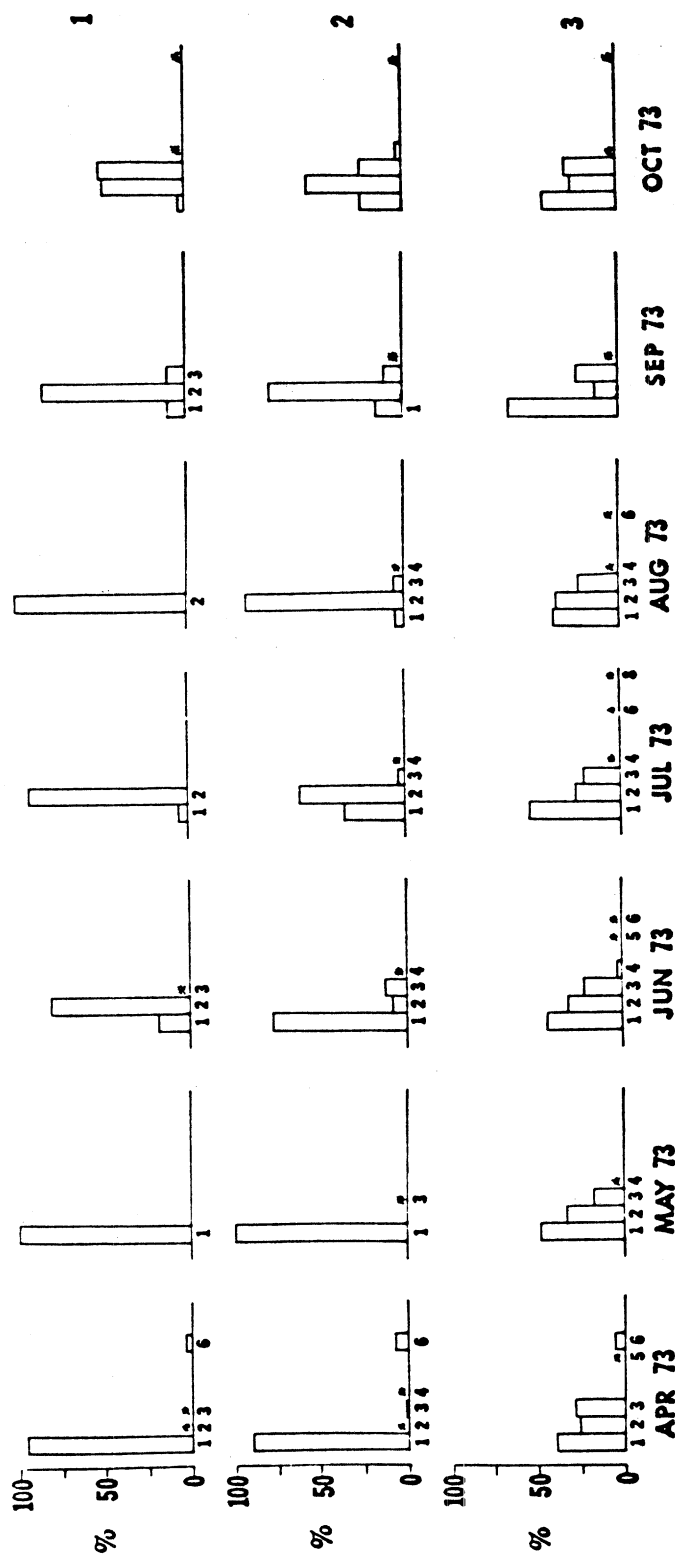


FIG. 21. Monthly size and reproductive-state classes of *Pontoporeia affinis* from benthic depth zones 1, 2 and 3 in 1973. "*" signifies <2% but >0. Classes: 1-<3 mm, 2-3 to 4.9 mm, 3-5 to 7 mm immature, 4->7 mm immature, 5-gravid females, 6-spent females, 7-mature males of the *filicornis*-type, 8-mature males of the *brevicornis*-type.

BENTHIC
ZONE

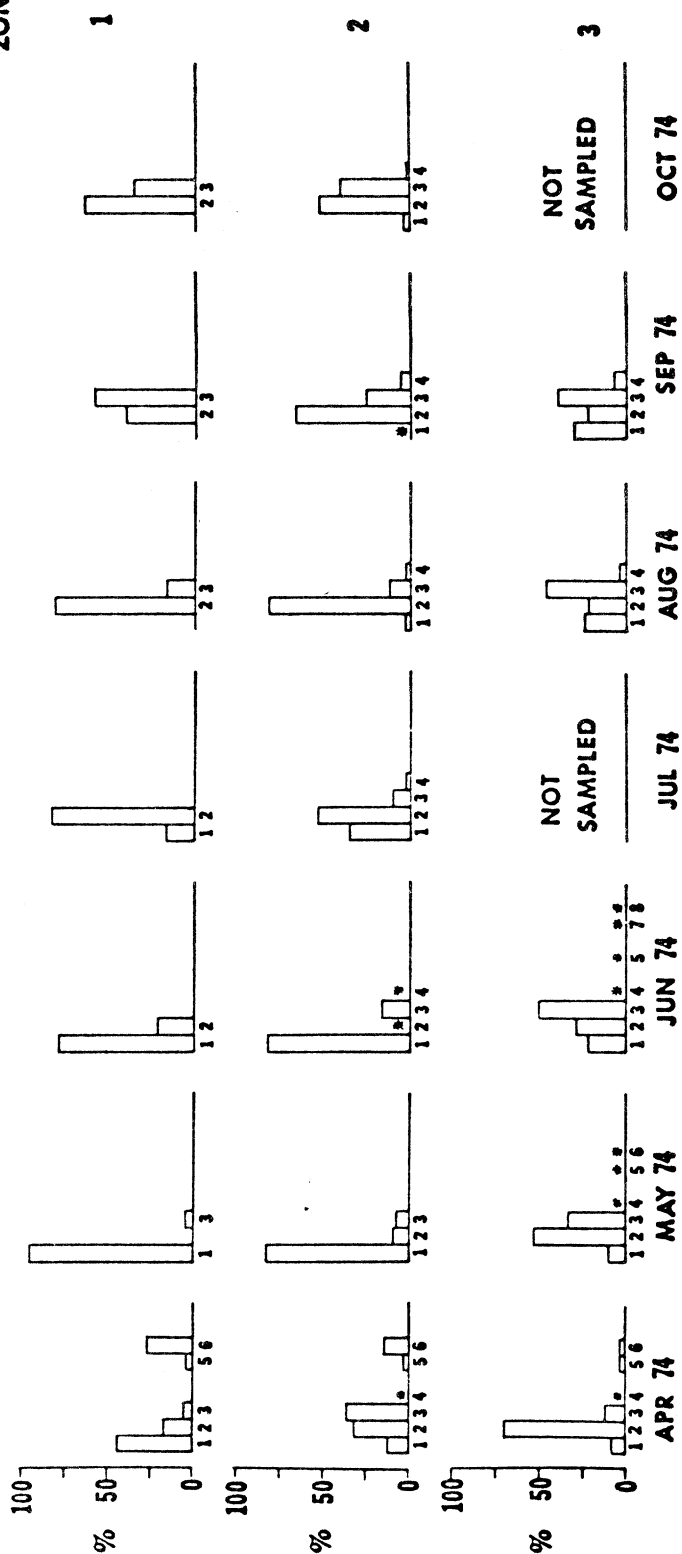


FIG. 22. Monthly size and reproductive-state classes of *Pontoporeia affinis* from benthic depth zones 1, 2 and 3 in 1974. "*" signifies <2% but >0. Classes: 1-<3 mm, 2-3 to 4.9 mm, 3-5 to 7 mm immature, 4->7 mm immature, 5-gravid females, 6-spent females, 7-mature males of the *filicornis*-type, 8-mature males of the *brevicornis*-type.

1974, however, and densities were more similar to those in 1972 than 1973. Moreover, specimens released in 1973 were a larger proportion of the 1974 populations in zones 2 and 3 than year-old individuals had been in previous years (Fig. 22).

Again in 1974 amphipod numbers decreased in late summer or fall, but decreases were proportionately less in 1974 and autumn densities were about the same in 1974 as in 1973. This regular autumn decline appears to result from a combination of offshore migration (increased occurrence above bottom at night in August, Mozley 1974) and seasonally elevated predation by fish. Analysis of stomach contents of yellow perch, smelt, troutperch and spottail shiners collected in 1973 (unpublished data) has revealed a pronounced increase in the frequency of occurrence and contribution to total food volume by *Pontoporeia* in September over August levels.

INNER-OUTER GRAPHICAL COMPARISONS

Johnston (1973) compared seasonal abundances of zoobenthos in the central region of the Cook survey area with those in the reference regions for each of the three shallower depth zones (A=0, B=1, C=2). Regional abundance graphs (Figs. 4-12) also indicated considerable variation in relative quantities of animals between the two groups of stations. Such comparisons will serve as an important early indicator of zoobenthic changes localized near the Cook Plant (Johnston 1973). To illustrate these relationships more clearly, data already presented are rearranged to conform with Johnston's graphs.

Graphs are given for most of the major taxonomic groups, as well as for total counts (Fig. 23). All major surveys, including those conducted on the grid design from July 1970 through April 1972 and in July and October 1974 are illustrated. Short surveys contain insufficient "outer" stations for inclusion in this form of presentation. Fall (November) 1971 data were omitted because inclement weather prevented sampling at most outer stations. Data from July and October 1974 major surveys, which were taken on the radial grid in such a way as to permit continued inner-outer comparisons, are given in Tables 7 and 8.

Pontoporeia affinis populations usually underwent similar fluctuations at inner and outer stations (Fig. 24). Moreover, this species was rather evenly distributed within each set of stations, resulting in narrower error

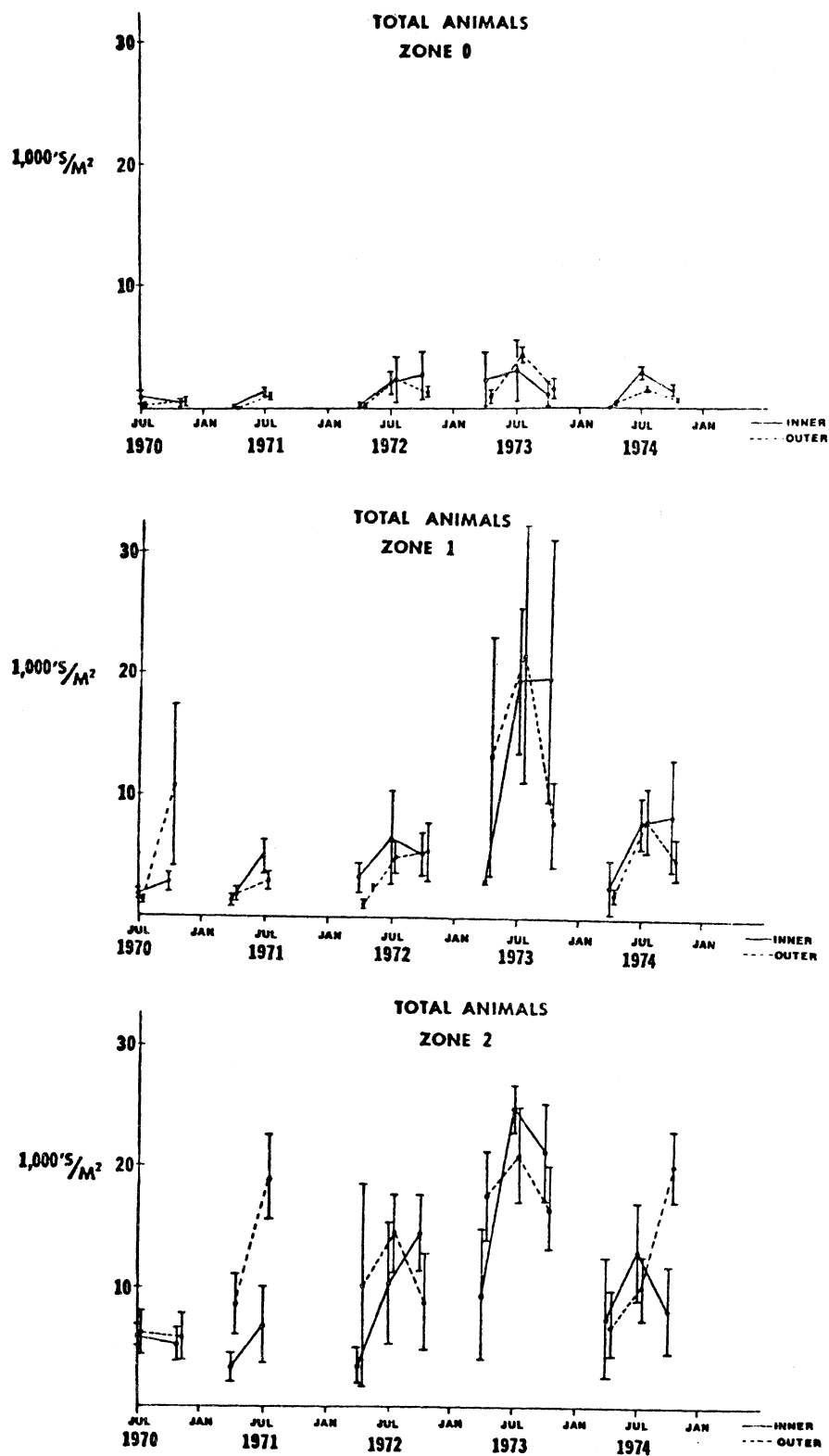


FIG. 23. Means and standard errors (brackets) for inner-outer comparisons of total animals in benthic depth zones 0, 1 and 2, 1970-74.

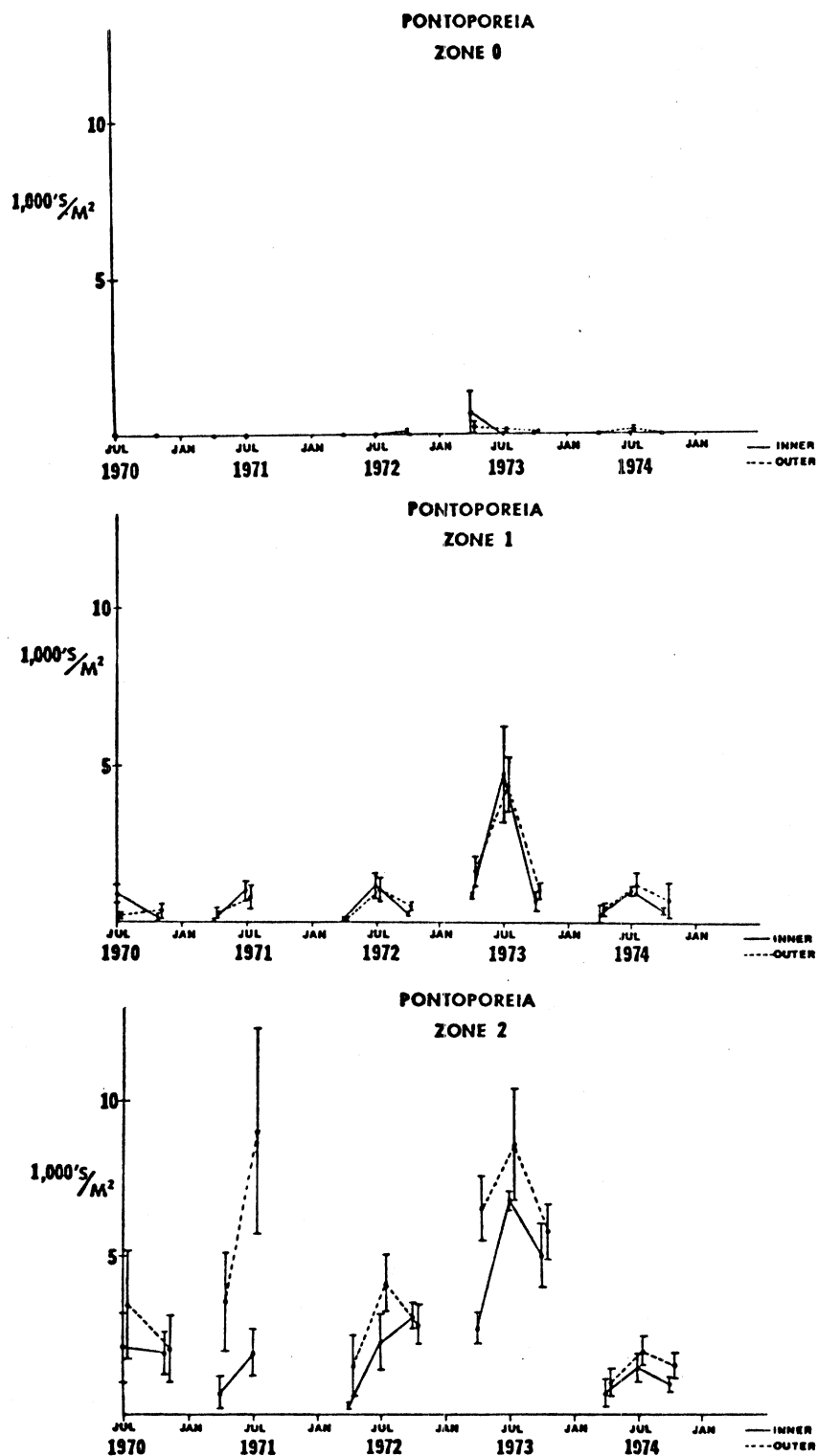


FIG. 24. Means and standard errors (brackets) for inner-outer comparisons of *Pontoporeia affinis* in benthic depth zones 0, 1 and 2, 1970-74.

TABLE 7. Station means and standard errors¹ for major taxa of zoobenthos in the July 1974 major survey. Units are numbers per m².

Taxon	Zone 0 - Inner				
	SDC 1-1 (4)	SDC .5-1 (4)	DC-1 (4)	NDC .5-1 (4)	NDC 1-1 (4)
<i>P. affinis</i>	0	75.8±75.8	45.4±29.1	0	15.2±15.2
Tubificidae	60.6±42.7	318±117	45.4±29.1	15.2±15.2	848±358
Naididae	667±124	545±49.4	152±72.1	333±134	2227±1082
<i>Stylodrilus</i>	0	0	0	0	0
<i>S. nitidum</i>	0	0	0	0	0
<i>S. striatinum</i>	0	0	0	0	0
<i>Pisidium</i> spp	0	0	15.2±15.2	0	60.6±60.6
Chironomidae	1954±380	2530±431	1273±74.2	1106±97.0	1167±100
Hirudinea	0	0	0	0	0
Operculata	0	0	0	0	0
Pulmonata	0	15.2±15.2	0	0	0
Other	90.9±17.6	15.2±15.2	0	30.3±30.3	75.8±15.2
Total Animals	2772±457	3500±433	1530±122	1485±134	4394±1440

Taxon	Zone 0 - Outer				
	SDC 7-1 (4)	SDC 4-1 (4)	SDC 2-1 (4)	NDC 4-1 (4)	NDC 7-1 (4)
<i>P. affinis</i>	0	0	15.2±15.2	651±552	0
Tubificidae	30.3±17.6	15.2±15.2	15.2±15.2	45.5±15.2	30.3±30.3
Naididae	212±112	75.8±38.2	348±75.8	712±295	591±341
<i>Stylodrilus</i>	0	0	0	15.2±15.2	0
<i>S. nitidum</i>	0	0	0	0	0
<i>S. striatinum</i>	0	0	0	0	0
<i>Pisidium</i> spp.	0	0	0	45.5±45.5	0
Chironomidae	894±216	1000±127	1364±181	909±156	333±80.3
Hirudinea	0	0	0	0	0
Operculata	0	0	0	0	0
Pulmonata	0	0	0	0	0
Other	15.2±15.2	0	0	0	0
Total Animals	1151±329	1091±166	1742±220	2379±489	954±448

¹ 95% confidence intervals = t._{.05} times the standard error. In zone 0, t._{.05} (3 d.f.) = 3.2, in zones 1-2, t._{.05} (1 d.f.) = 12.7.

TABLE 7 continued.

Taxon	Zone 1 - Inner				
	SDC 1-2 (2)	SDC .25-1 (2)	DC-2 (2)	NDC .25-1 (2)	ND 1-2 (2)
<i>P. affinis</i>	1333±1212	789±545	1212±121	545±121	1212±364
Tubificidae	4091±939	4727±1818	2394±576	636±333	1061±90.8
Naididae	333±333	636±515	303±60.4	90.9±30.4	545±182
<i>Stylodrilus</i>	60.6±60.6	30.3±30.3	60.6±60.6	30.3±30.3	0
<i>S. nitidum</i>	60.6±60.6	90.9±90.9	0	0	0
<i>S. striatinum</i>	90.9±90.9	60.6±00.0	30.3±30.3	0	30.3±30.3
<i>Pisidium</i> spp.	697±152	1364±939	848±121	60.6±60.6	394±273
Chironomidae	2363±424	7151±5394	939±90.8	697±152	4181±1757
Hirudinea	0	121±60.4	0	0	90.9±90.9
Operculata	90.9±90.9	30.3±30.3	60.6±60.6	60.6±60.6	60.6±60.6
Pulmonata	0	0	30.3±30.3	0	30.3±30.3
Other	0	30.3±30.3	90.9±90.9	0	30.3±30.3
Total Animals	9120±333	15029±8060	5969±818	2121±485	7636±2727

Taxon	Zone 1 - Outer				
	SDC 7-3 (2)	SDC 7-2 (2)	SDC 2-3 (2)	NDC 2-3 (2)	NDC 7-3 (2)
<i>P. affinis</i>	2182±182	333±212	1182±455	1697±667	758±455
Tubificidae	4515±333	939±273	1151±485	13756±10666	6878±697
Naididae	333±90.8	152±30.4	0	121± 0	212±152
<i>Stylodrilus</i>	90.9±90.9	30.3±30.3	30.3±30.3	30.3±30.3	30.3±30.3
<i>S. nitidum</i>	60.6±60.6	60.6± 0	0	30.3±30.3	30.3±30.3
<i>S. striatinum</i>	0	90.9±30.4	0	0	0
<i>Pisidium</i> spp.	727±60.4	60.6± 0	121±121	242±121	394±212
Chironomidae	2485±243	606±60.4	364±60.4	818±455	152±152
Hirudinea	0	0	0	0	60.6± 0
Operculata	0	0	0	0	30.3±30.3
Pulmonata	0	0	0	0	0
Other	121±121	0	30.3±30.3	121±60.4	212±30.4
Total Animals	10514±90.8	2273±90.8	2879±1061	16816±10514	8757±30.4

TABLE 7 continued.

Taxon	Zone 2 - Inner				
	SDC 1-3 (2)	SDC .5-3 (2)	DC-3 (2)	DC-4 (2)	NDC .5-3 (2)
<i>P. affinis</i>	1030± 0	1000±212	394±212	1909±1121	485±60.4
Tubificidae	2454±1485	879±212	2242±970	18059±15332	2121±364
Naididae	60.6±60.6	30.3±30.3	30.3±30.3	90.9±30.4	182± 0
<i>Stylodrilus</i>	1667±576	0	90.9±30.4	1576±788	152±152
<i>S. nitidum</i>	90.9±90.9	0	0	0	30.3±30.3
<i>S. striatinum</i>	0	0	0	0	90.9±30.4
<i>Pisidium</i> spp.	1394±727	303±182	576±394	515±394	1303±939
Chironomidae	182±60.4	242±182	758±30.4	515±394	424± 0
Hirudinea	0	0	30.3±30.3	0	0
Operculata	0	30.3±30.3	0	60.6±60.6	60.6± 0
Pulmonata	0	30.3±30.3	0	0	0
Other	0	0	0	30.3±30.3	90.9±30.4
Total Animals	6879±3000	2515±455	4122±1151	22756±15847	4940±1545

Taxon	Zone 2 - Outer				
	SDC 7-5 (2)	SDC 7-4 (2)	SDC 4-3 (2)	NDC 4-3 (2)	NDC 7-5 (2)
<i>P. affinis</i>	1545±394	2333±273	879±273	455±212	2606±970
Tubificidae	8787±5817	1757±60.4	12332±5969	21634±20543	7817±1273
Naididae	0	30.3±30.3	242±60.4	60.6± 0	0
<i>Stylodrilus</i>	3151±1515	2454±818	2636±2394	1454±1454	3454±182
<i>S. nitidum</i>	0	303±243	273±30.4	0	939±212
<i>S. striatinum</i>	182±121	0	30.3±30.3	0	0
<i>Pisidium</i> spp.	6878±2030	1606±273	7030±60.4	60.6± 0	5363±636
Chironomidae	455±212	152±30.4	909±182	333±333	182±121
Hirudinea	0	30.3±30.3	30.3±30.3	0	90.9±30.4
Operculata	121±60.4	273±152	424±121	0	606±364
Pulmonata	0	152±30.4	30.3±30.3	0	0
Other	0	30.3±30.3	0	30.3±30.3	60.6± 0
Total Animals	21119±10150	9121±1000	24816±3485	24028±22150	21119±2394

TABLE 8. Station means and standard errors¹ for major taxa of zoobenthos in the October 1974 major survey. Units are numbers per m².

Taxon	Zone 0 - Inner				
	SDC 1-1 (4)	SDC .5-1 (4)	DC-1 (4)	NDC .5-1 (4)	NDC 1-1 (4)
<i>P. affinis</i>	0	45.5±29.1	0	15.2±15.2	0
Tubificidae	576±143	318±155	45.4±29.1	197±129	682±344
Naididae	45.5±15.2	30.3±17.6	0	0	75.8±75.8
<i>Stylodrilus</i>	0	0	0	15.2±15.2	15.2±15.2
<i>S. nitidum</i>	0	0	0	0	0
<i>S. striatinum</i>	0	0	0	0	0
<i>Pisidium</i> spp.	0	45.5±15.2	45.5±29.1	30.3±17.6	15.2±15.2
Chironomidae	1530±616	2363±823	258±51.8	182±78.2	90.9±17.6
Hirudinea	15.2±15.2	0	15.2±15.2	0	30.3±30.3
Operculata	0	15.2±15.2	0	0	0
Pulmonata	0	0	0	0	0
Other	0	0	0	0	0
Total Animals	2167±600	2817±955	364±113	440±103	909±446

Taxon	Zone 0 - Outer				
	SDC 7-1 (4)	SDC 4-1 (4)	SDC 2-1 (4)	NDC 4-1 (4)	NDC 7-1 (4)
<i>P. affinis</i>	0	0	0	0	0
Tubificidae	106±62.4	0	106±67.3	121±24.9	167±97.0
Naididae	0	0	0	0	15.2±15.2
<i>Stylodrilus</i>	45.4±29.1	0	0	15.2±15.2	0
<i>S. nitidum</i>	0	0	0	0	0
<i>S. striatinum</i>	15.2±15.2	0	0	0	0
<i>Pisidium</i> spp.	75.8±45.5	15.2±15.2	0	15.2±15.2	0
Chironomidae	606±214	45.5±15.2	954±470	227±51.8	182±55.5
Hirudinea	0	15.2±15.2	15.2±15.2	0	15.2±15.2
Operculata	0	30.3±30.3	75.8±45.5	0	0
Pulmonata	0	0	0	0	0
Other	0	0	0	0	0
Total Animals	849±291	106±51.8	1151±516	378±51.8	379±149

¹ 95% confidence intervals = t_{.05} times the standard error. In zone 0, t_{.05} (3 d.f.) = 3.2, in zones 1-2, t_{.05} (1 d.f.) = 12.7.

TABLE 8 continued.

Taxon	Zone 1 - Inner				
	SDC 1-2 (2)	SDC .25-1 (2)	DC-2 (2)	NDC .25-1 (2)	NDC 1-2 (2)
<i>P. affinis</i>	182±121	697±212	515±30.4	121±121	333±90.8
Tubificidae	6727±1818	909±424	1364±455	20877±4151	576±212
Naididae	182±60.4	0	121±60.4	121±121	30.3±30.3
<i>Stylodrilus</i>	90.9±90.9	60.6± 0	0	30.3±30.3	0
<i>S. nitidum</i>	60.6± 0	0	0	90.9±90.9	0
<i>S. striatinum</i>	60.6± 0	0	0	0	30.3±30.3
<i>Pisidium</i> spp.	545±303	303±121	788± 0	3272±2242	727±545
Chironomidae	758±394	364±182	121±121	1879±243	364±121
Hirudinea	182±182	30.3±30.3	0	242±60.4	30.3±30.3
Operculata	121±60.4	0	30.3±30.3	152±15.2	0
Pulmonata	0	0	0	0	0
Other	121±121	0	30.3±30.3	60.6±60.6	30.3±30.3
Total Animals	9030±970	2364±727	2970±667	26846±1151	2121±848

Taxon	Zone 1 - Outer				
	SDC 7-3 (2)	SDC 7-2 (2)	SDC 2-3 (2)	NDC 2-3 (2)	NDC 7-3 (2)
<i>P. affinis</i>	1485±212	273±30.4	303±243	364±121	1091±121
Tubificidae	3333±121	2091±818	515±394	424±121	6939±2030
Naididae	30.3±30.3	212±90.8	0	0	90.9±90.9
<i>Stylodrilus</i>	90.9±90.9	0	30.3±30.3	30.3±30.3	515±212
<i>S. nitidum</i>	0	0	30.3±30.3	0	0
<i>S. striatinum</i>	0	30.3±30.3	0	30.3±30.3	0
<i>Pisidium</i> spp.	606±121	576±273	606±545	303±182	1879±121
Chironomidae	424±60.4	394±30.4	394±394	394±152	485±243
Hirudinea	60.6± 0	60.6±60.6	0	30.3±30.3	60.6±60.6
Operculata	0	0	30.3±30.3	30.3±30.3	152±90.8
Pulmonata	0	0	0	60.6±60.6	30.3±30.3
Other	90.9±30.4	60.6±60.6	0	0	30.3±30.3
Total Animals	6121±182	3698±545	1909±1666	1667±90.8	11273±2242

TABLE 8 continued.

Taxon	Zone 2 - Inner				
	SDC 1-3 (2)	SDC .5-3 (2)	DC-3 (2)	DC-4 (2)	NDC .5-3 (2)
<i>P. affinis</i>	2848±1091	2030±152	212±90.8	1394±1030	848±121
Tubificidae	2545±2000	1757±909	4303±3818	12484±11635	21180±17604
Naididae	30.3±30.3	90.9±90.9	60.6±60.6	515±394	30.3±30.3
<i>Stylodrilus</i>	1818±1273	152±30.4	394±394	606±606	90.9±30.4
<i>S. nitidum</i>	121±121	0	121±121	152±90.8	60.6± 0
<i>S. striatinum</i>	0	0	152±152	0	60.6±60.6
<i>Pisidium</i> spp.	909±545	60.6±60.6	1485±1485	1515±848	3575±2000
Chironomidae	152±30.4	1000±515	485±182	90.9±30.4	30.3±30.3
Hirudinea	30.3±30.3	30.3±30.3	182±182	0	152±30.4
Operculata	0	0	0	121±121	121±121
Pulmonata	0	30.3±30.3	0	0	30.3±30.3
Other	121±60.4	394±30.4	30.3±30.3	364±243	212±152
Total Animals	8575±5182	5545±1485	7425±6212	17242±11666	26391±19786

Taxon	Zone 2 - Outer				
	SDC 7-5 (2)	SDC 7-4 (2)	SDC 4-3 (2)	NDC 4-3 (2)	NDC 7-5 (2)
<i>P. affinis</i>	2757±212	3303±1727	606±303	1667±394	1545±758
Tubificidae	7908±152	697±455	9938±6545	182±121	4727±3636
Naididae	30.3±30.3	152±90.8	303±121	0	30.3±30.3
<i>Stylodrilus</i>	3606±2515	90.9±30.4	939±30.4	152±30.4	4757±4393
<i>S. nitidum</i>	30.3±30.3	0	212±30.4	0	454±333
<i>S. striatinum</i>	0	0	30.3±30.3	0	0
<i>Pisidium</i> spp.	636±152	212±30.4	1818±243	0	2485±1636
Chironomidae	121± 0	364±182	30.3±30.3	30.3±30.3	90.9±30.4
Hirudinea	30.3±30.3	0	0	0	0
Operculata	0	30.3±30.3	212±90.8	0	121±121
Pulmonata	0	0	60.6±60.6	0	0
Other	121± 0	30.3±30.3	60.6± 0	0	0
Total Animals	15240±2333	4880±2394	14210±7242	2031±333	14210±10938

bars around the means than were obtained for other taxa. Data from zone 1 (B) were the least variable of any zone of inner and outer stations, and most similar between inner and outer stations. *Pontoporeia* occurred in zone 0 (A) rarely, except in summer, and numbers were quite variable within sets in zone 2 (C). Larger populations in the north reference region (Fig. 5) elevated means of outer stations above those for inner stations most of the time.

Tubificidae were far less consistent (Fig. 25). These worms varied broadly within sets of stations, and seasonal patterns of mean numbers were dissimilar between both inner and outer stations and from year to year within each set.

Stylodrilus heringianus was also inconsistent in annual and regional patterns (Fig. 26). Differences between inner and outer stations were more evident for *Stylodrilus* than for Tubificidae, as standard errors overlapped less often and seasonal trends in mean numbers were more similar from year to year after 1970, but larger populations occurred sometimes at inner, and other times at outer stations. Zone 0 (A) data for *Stylodrilus* were omitted because occurrence of the species at those depths was rare and irregular.

Pisidium ranked after *Pontoporeia* in degree of similarity between inner and outer stations in zone 1 (B) (Fig. 27). Too few individuals occurred in zone 0, and variability within and between inner and outer sets of stations was large and irregular in zone 2, so that fingernail clams offered little value as quantitative measures of environmental effects at those depths.

Chironomidae species were the dominant benthic invertebrates in zone 0 (A), but unfortunately their abundances were variable within both sets of stations (Fig. 28). Seasonal patterns, however, were generally similar from year to year. Peak numbers occurred at both inner and outer stations in July (exception--outer stations in 1972). Inner stations had either similar or larger numbers of midgefly larvae compared to outer stations. Variability in the data was positively correlated with the means, suggesting that transformation of the data, as Johnston (1973) recommended, might be beneficial. Chironomid data from zones 1 and 2 were less useful for inner/outer comparisons because seasonal trends were less similar between inner and outer stations. Ranges of seasonal means were most similar from year to year in zone 2, however. Zone 1 estimates from the 1974

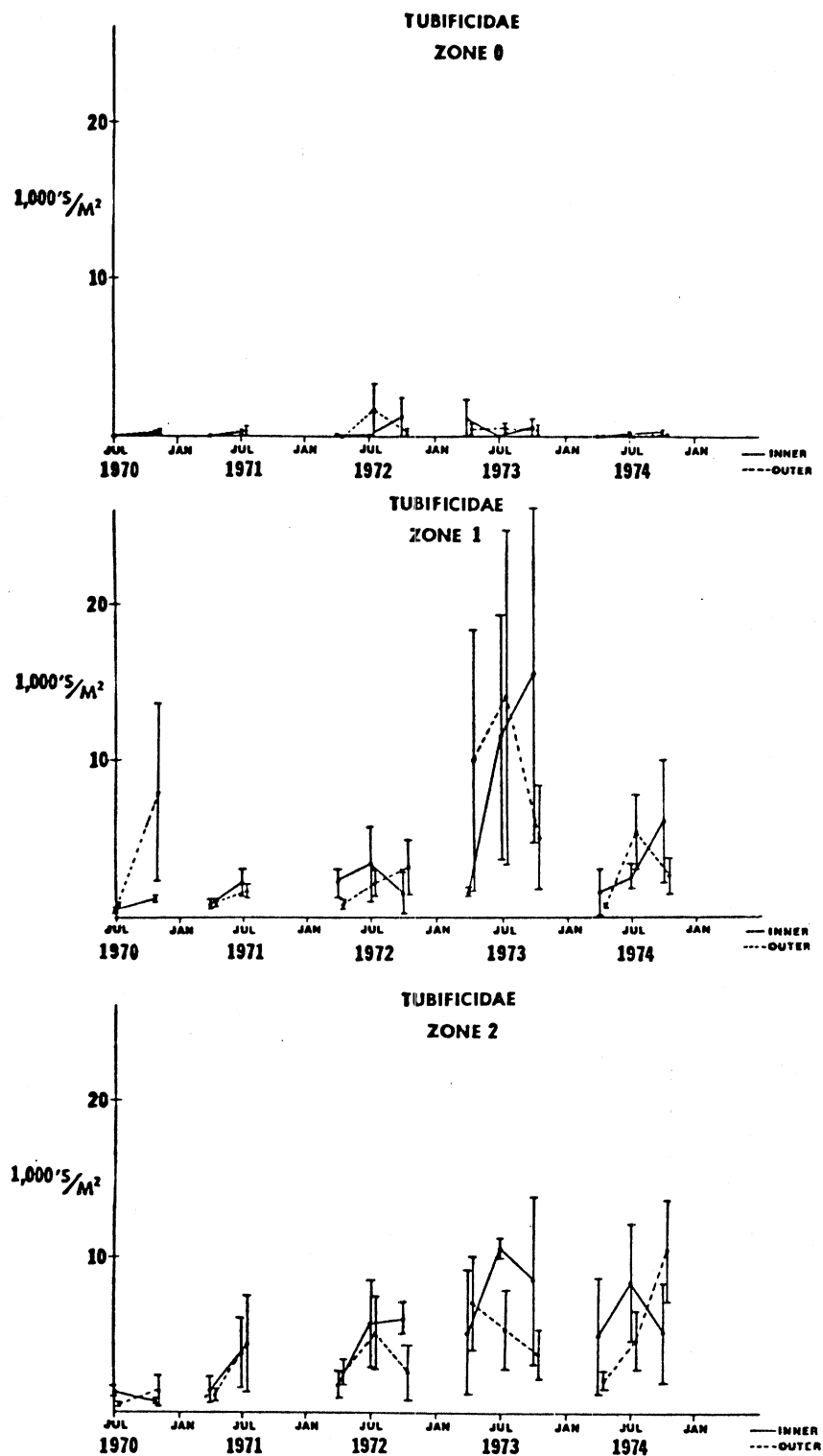


FIG. 25. Means and standard errors (brackets) for inner-outer comparisons of total Tubificidae in benthic depth zones 0, 1 and 2, 1970-74.

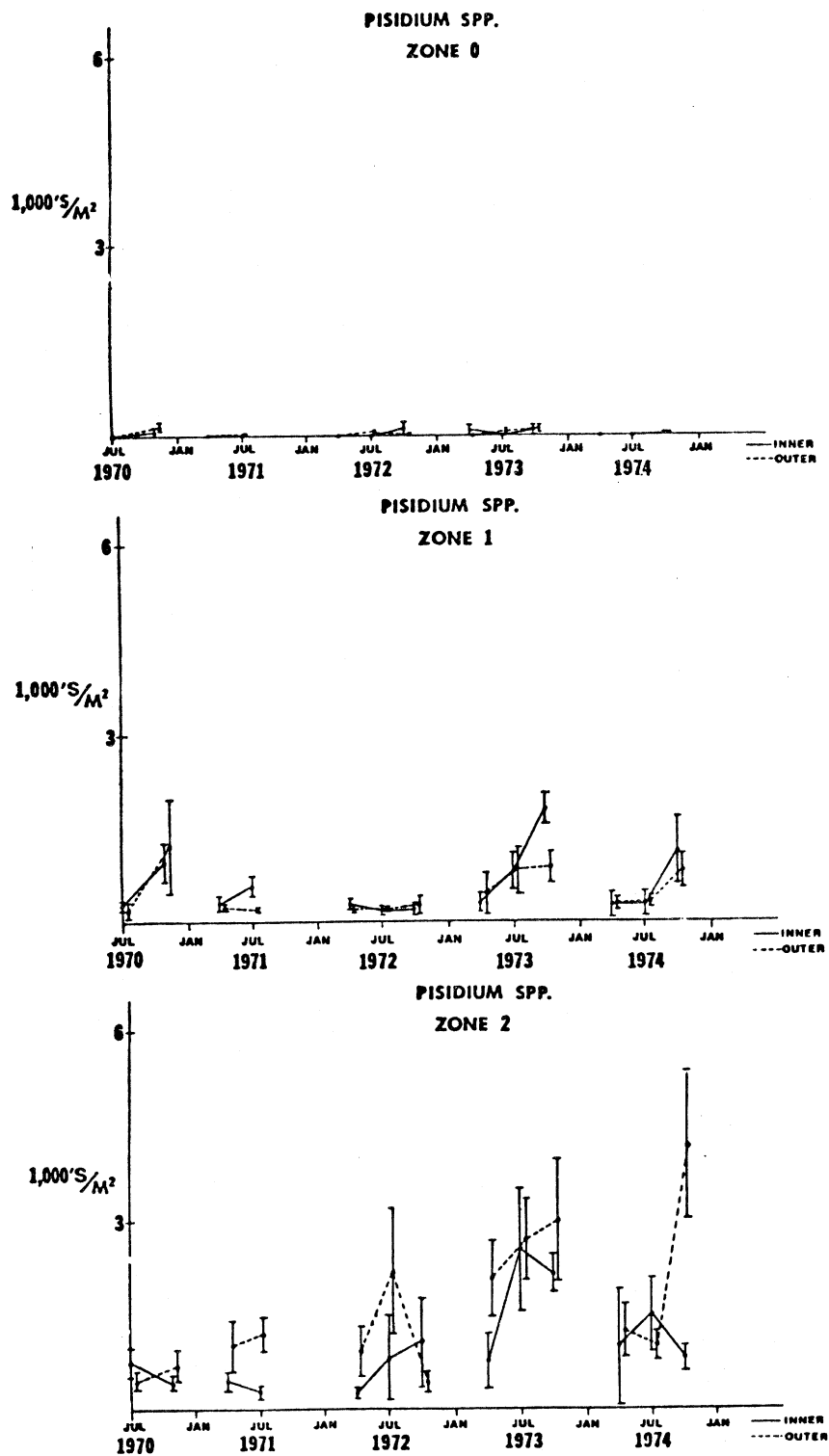


FIG. 26. Means and standard errors (brackets) for inner-outer comparisons of total *Pisidium* in benthic depth zones 0, 1 and 2, 1970-74.

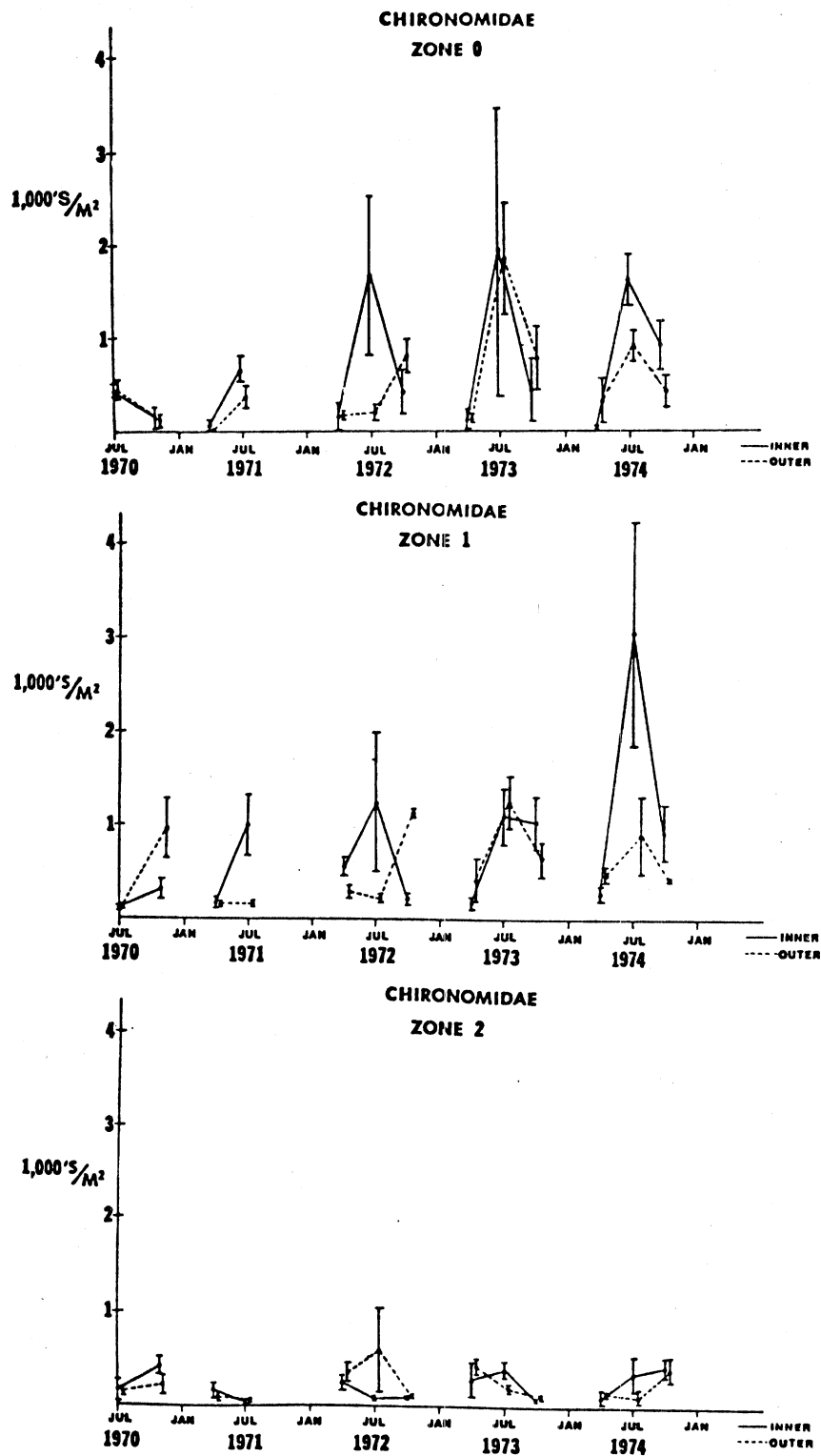


FIG. 27. Means and standard errors (brackets) for inner-outer comparisons of total Chironomidae in benthic depth zones 0, 1 and 2, 1970-74.

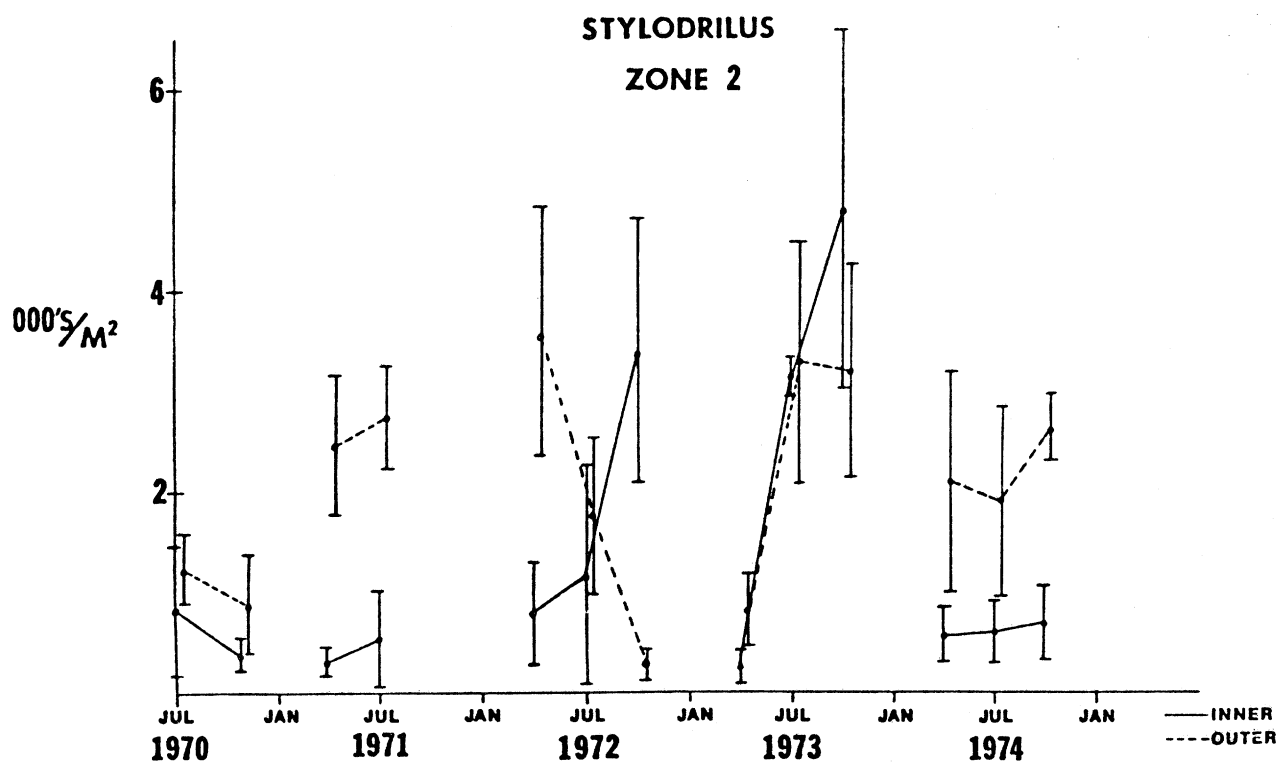
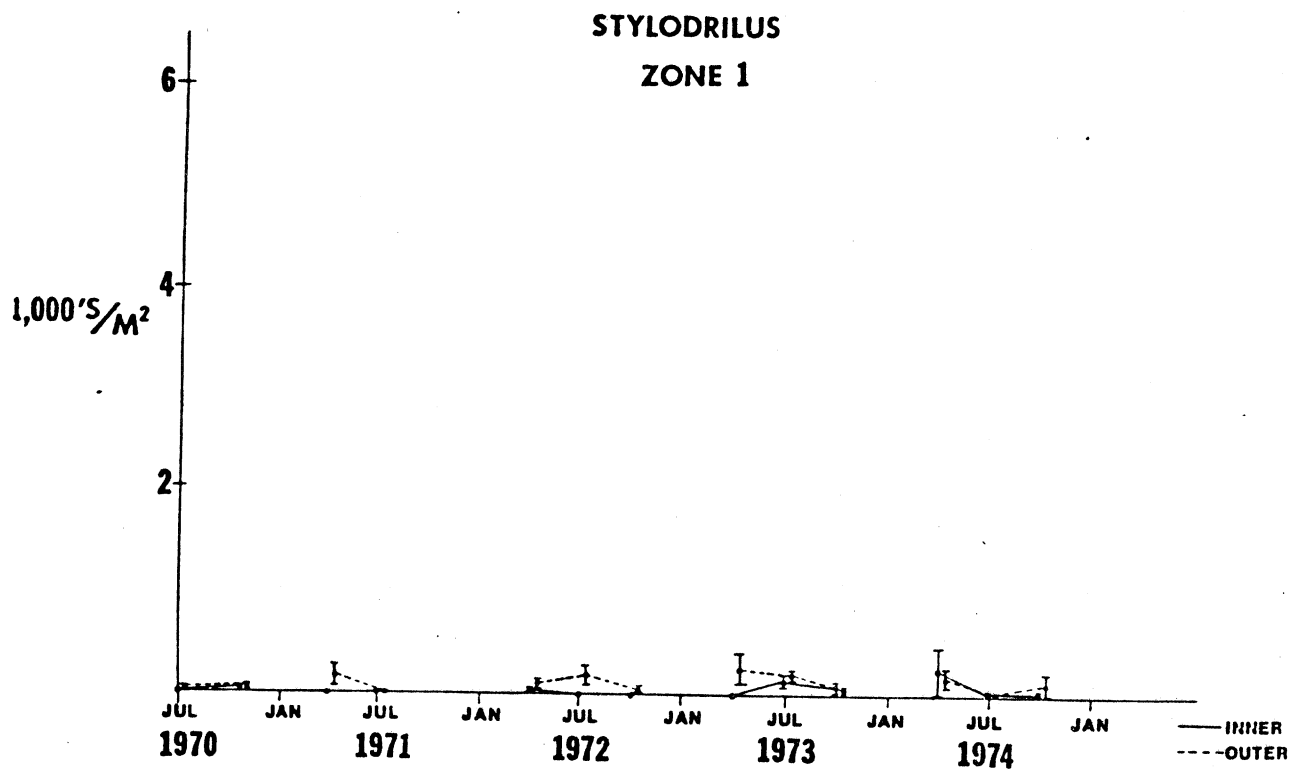


FIG. 28. Means and standard errors (brackets) for inner-outer comparisons of *Stylodrilus heringanus* in benthic depth zones 1 and 2, 1970-74.

survey indicated a large increase in chironomids at inner stations. This coincided with a reduction in *Pontoporeia* numbers from a 1973 maximum. As both taxa feed on fine, surficial detritus, competitive interactions may have contributed to the approximately reciprocal changes in population sizes.

Total counts of benthic macroinvertebrates continued trends noted by Johnston (1973) for 1970-72 in 1973 and 1974 (Fig. 23). Temporal variations or errors about seasonal means due to year-to-year differences exceeded or equaled spatial variations and set an upper limit to the benefits which might be achieved in precision by increasing the number of replicate observations within inner and outer sets of stations on each survey.

The best hope for useful application of the graphical techniques for early detection of plant effects appeared to be *Pontoporeia* populations. Unlike the data on Chironomidae, *Pontoporeia* data had the added advantages of being more fully representative of the true population, and taxonomically uniform.

Chironomidae were composed of mixed species, and large proportions of common species were lost through the screens when samples were sieved (see Methodological Studies). Nevertheless, midge larvae were the only taxon represented year-round at the depth of the plant's discharge structures (6 m), and as such provide the only possible indicators of environmental change. At least one larval type was sufficiently large and present in benthic depth zone 0 with enough regularity to be amenable for inner-outer comparisons, *Chironomus fluviatilis*-form. The appended word "-form" is used to indicate that the larvae have a certain type of blood gills (straight, tapered to a point). Identification of *Chironomus* larvae to species is not possible on the basis of external morphology.

Seasonal variations of *Chironomus fluviatilis*-form at inner and outer stations were generally similar (Fig. 29). Seasonal patterns differed between inner and outer stations in 1971 in zone 1 and in 1973 in zone 0, however. Zone 0 differences in 1973 may have been due to sampling errors (broad error brackets indicate large differences among replicate observations), but zone 1 1971 differences appear to have been significant (distinctly non-overlapping standard errors) in both July and November. Monthly data from 1972 and 1973 showed that *Chironomus fluviatilis*-form emerged in spring,

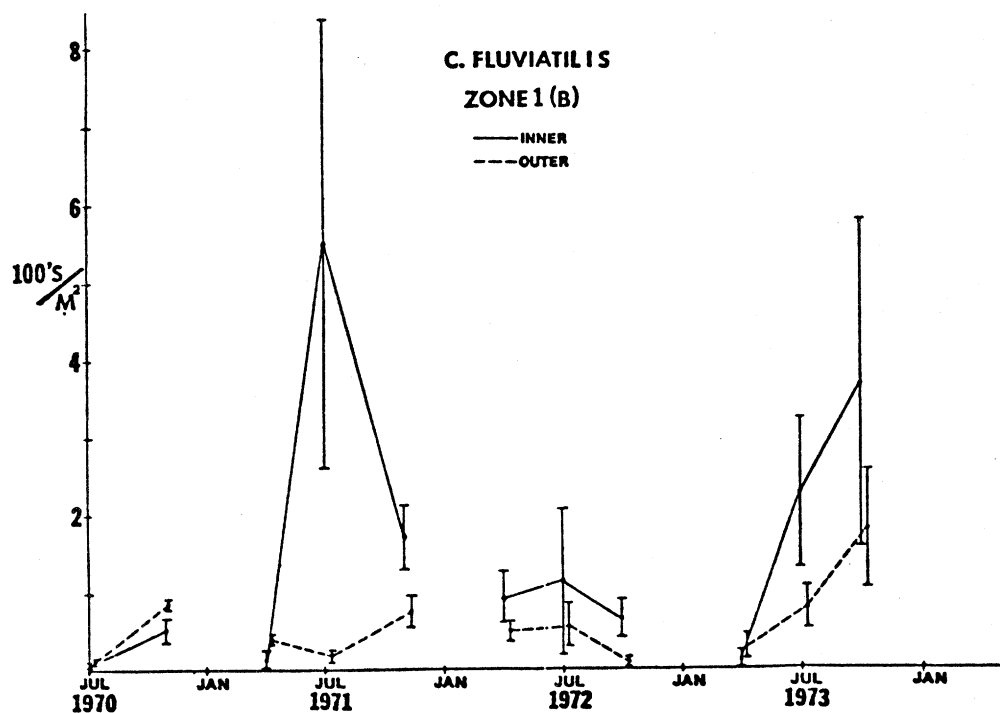
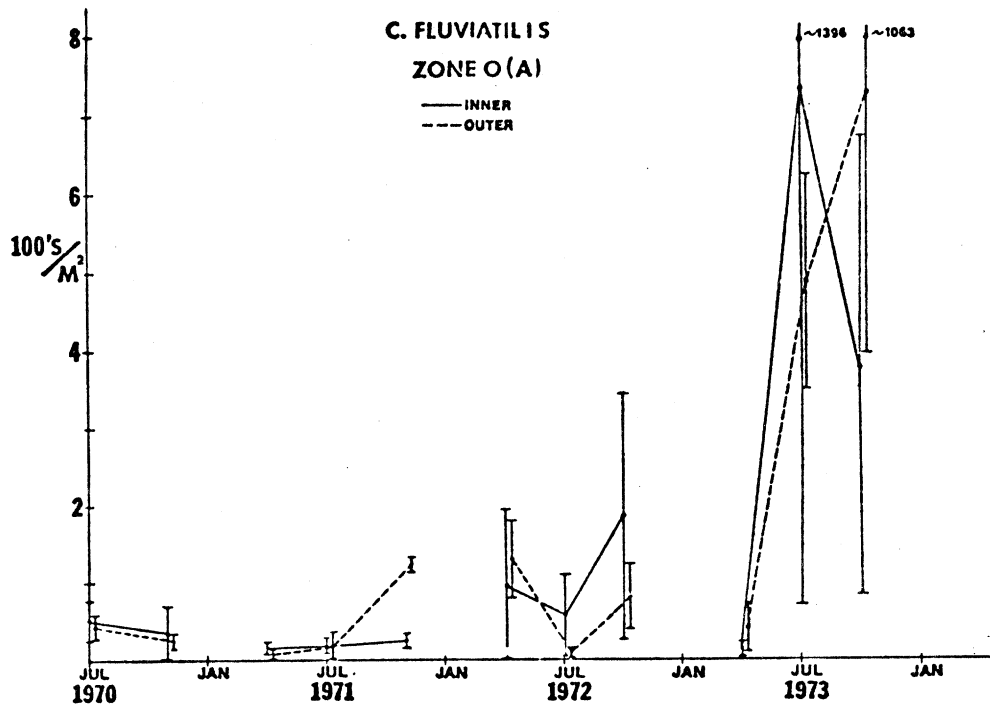


FIG. 29. Means and standard errors for inner-outer comparisons of *Chironomus fluviatilis*-form larvae in benthic depth zones 0 and 1, 1970-1973.

and reappeared as younger instars in midsummer (see Seasonal Abundance of Common Chironomidae, 0-16 m). The degree to which seasonal, major surveys reflected this pattern depended apparently on whether the July survey occurred before or after summer increases had begun. Differences between inner and outer stations such as those observed in July 1971 could result from phase differences of perhaps as little as a week in *Chironomus* populations in the different areas.

Another probable source of large sampling errors in major surveys conducted by the systematic-random design was the acute dependence of *Chironomus* abundance on the depth within zone 0. If a randomly selected station location fell at a depth less than 3 m, few if any macroinvertebrates occurred in the grab casts while only a few hundred meters farther from shore at a depth of 6 m, an average cast of the grab would retrieve 10 or more larvae. Averages of stations within zone 0 had larger associated standard errors when some stations (locations selected at random) were less than 3 m deep. Moreover, if inner stations happened to fall at depths less than 6 m but outer stations fell in the range 6-8 m, pronounced differences between sample means could arise when in fact there were no differences in *Chironomus* populations in the two zones represented by the stations.

Even though the relationship between inner and outer means varied due to sampling error, design problems and possibly real changes in the populations, *Chironomus* third and fourth instars were the only zoobenthos in zone 0 which were retained completely on the 0.5-mm screen, and were present in sufficient numbers to support inner-outer comparisons.

ENTRAINMENT STUDIES

TESTS FOR HETEROGENEITY IN THE INTAKE FOREBAY

Entrainment collections in 1974 were designed to determine whether horizontal or vertical location in the intake forebay, or time of day, affected estimates of the numbers of zoobenthos passing through the plant. For 1974 tests, pumps feeding Unit 1 of the eventually two-unit Cook Plant were operated without addition of heat from the condensers (Table 9).

Samples were collected from the forebay with "80-gallon-per-minute"

TABLE 9. Conditions and specifications of 1974 studies of vertical, horizontal and diel heterogeneity of densities of entrained zoobenthos in the intake forebay of the Cook Plant. Location (grate) numbers refer to Fig. 27. Depths are reckoned from the water surface. (D) = day, (N) = night.

Month	Cooling		Intake temp. (C)	Sampling				Duration per pumped sample
	pumps running			Pumps	Locations	Depths (m)	Date/Time (EST)	
May	1	9.7 - 10.8		1	2,5	0.6, 6.2, 8.7	8/00:30-05:00 (N) 8/13:00-16:15 (D)	10 min.
July	3	13.9 - 14.0		2	5,7	0.6, 5.3, 10.8	23/13:00-15:20 (D) 23-24/22:00-00:30 (N)	15 min.
August	3	22.3		3	5, 6, 7	0.6, 5.6, 8.7	6-7/22:00-00:30 (N) 7/12:30-14:50 (D)	15 min.
November	1	6.7 - 7.2		3	1, 4, 6	5.6	20/16:00-22:00 (D) 20-21/23:00-07:00 (N)	6 hr. 8 hr.

diaphragm pumps. In practice, the pumps drew only 0.21-0.25 m³/min (55-65 gal/min). Hoses of 7.5 cm (3 inches) inside diameter were lowered from the pump to a predetermined depth at sites shown in Fig. 30. Water issuing from the pumps was strained through 0.35-mm (#2) screening, then run through a flowmeter, for a preset amount of time. Material caught in the nets was preserved in formalin, and examined later for fish larvae and eggs, as well as for zoobenthos. Fish data will be reported in a separate volume.

Three tests for heterogeneity, in May, July and August, differed to some degree in locations, depths, durations and numbers of observations (Table 9). In May, a single sampling pump was transferred manually from one location to the next. Each depth was sampled in sequence, then replicated in reverse sequence so that the 0.6-m depth replicates were taken more than an hour apart. In subsequent months, use of several sampling pumps simultaneously and immediate replication at each depth and location provided a more suitable data base.

The most abundant benthic animal in May collections was *Hydra americana*, while *Chironomus fluviatilis*-form was the most numerous among larger invertebrate taxa. Numerical data for these two forms were subjected to analysis of variance with the program BMD2V of the UCLA Biomedical Series. Data were transformed using $Y = \log_{10}(x + 1)$ before analysis. Only the day/night effect was significant at the 0.05 level or less ($p < 0.01$), a result consistent with the nocturnal migratory habits of *Chironomus*. Differences between means for the two sampling locations were relatively small. *Hydra* data produced no significant effects of locations, depths or day/night times at the 0.05 level. Only a single circulating water pump was operated at a time in May.

In July, four species from sandy habitats were common in entrainment samples, the chironomids *Chironomus fluviatilis*-form, *Paracladopelma tylus* and the naidids *Nais pardalis* and *Stylaria lacustris*. Examination of the data revealed that typical day/night differences in abundance were not well developed. Analysis of variance indicated no significant effects of location, depth or day/night times at the 0.05 level. The cause of disruption of normal migratory patterns was not evident.

Two weeks later, in early August, the most thorough 1974 test for heterogeneity was conducted. All three cooling system pumps of Unit 1 were operating. Three locations were sampled day and night at three depths each,

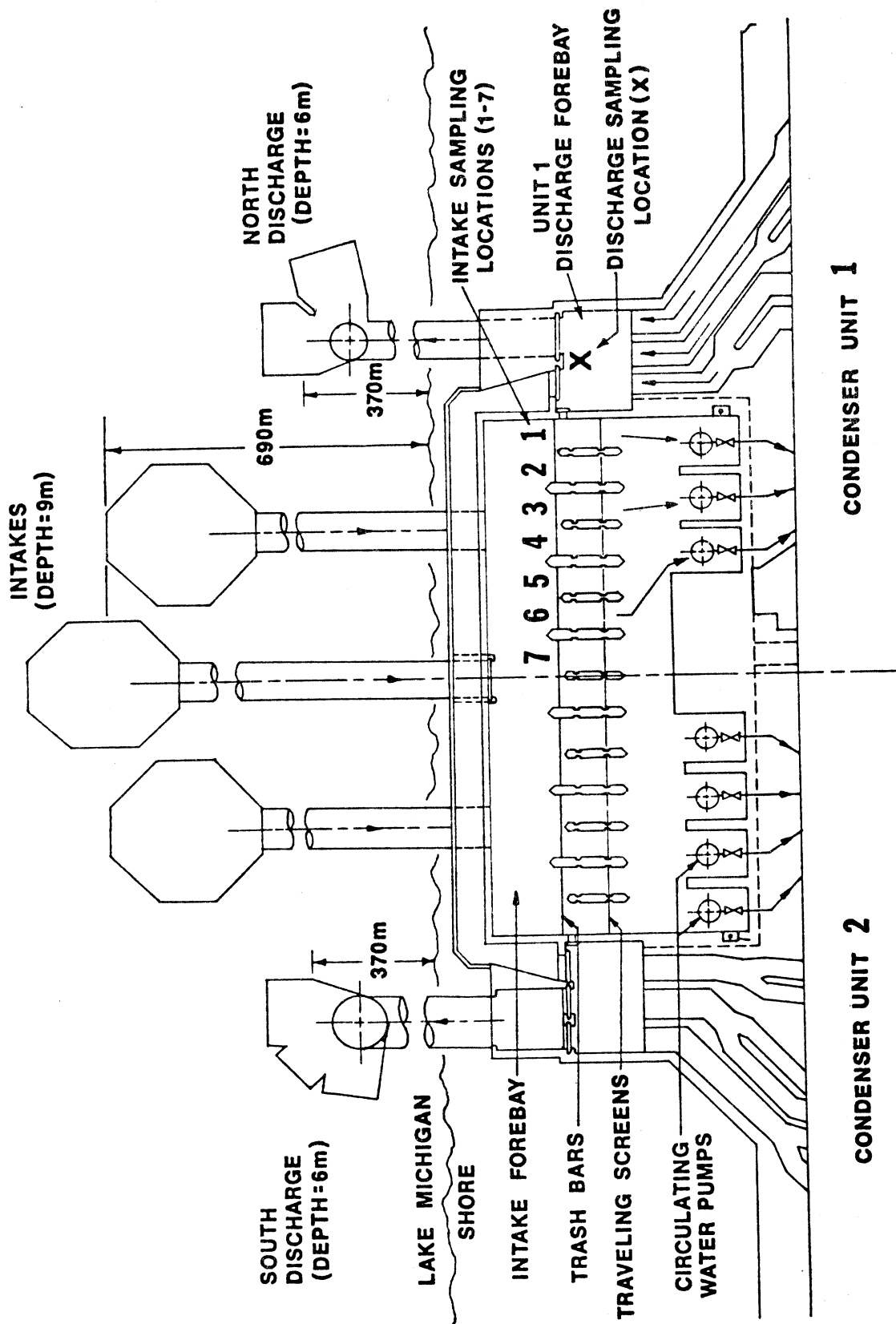


FIG. 30. Diagrammatic layout of the intake and discharge forebays of the Cook Plant, showing entrainment sampling locations 1-7.

and every observation was replicated once (Table 9). In addition to the species which were common in July, *Gammarus fasciatus* appeared frequently in August entrainment samples. Again, data were transformed using $Y = \ln(x + 1)$, and residuals provided by the BMD2V analysis of variance program were plotted versus the means to ensure validity of the analytical assumptions. Only night samples included sufficient non-zero observations for common species to support analysis. "Total-animals-minus-*Hydra*," however, did have sufficient day observations to permit day/night comparisons. *Hydra* were excluded because it was felt that most were growing on the walls of the intake system, and thus were not part of the lake benthos. This combined category showed significant effects for day/night times ($p < 0.01$) and depths ($p < 0.05$). Location (grate) effects were not significant at the 0.05 level, but the F-ratio was very close to the 0.05 significance level. Multiple range testing (Student-Newman-Keuls procedure, Zar 1974) was conducted (Table 10). Two species among those common in night samples showed significant or nearly significant grate or depth effects (Table 10). Strongest effects were observed for grates on *Chironomus fluviatilis*-form larvae. Grates 5 and 6 (Fig. 30) differed significantly ($p < 0.05$) from each other, but neither was different from grate 7 in effects on total-animals-minus-*Hydra*, and grates 6 and 7 had significantly more *Chironomus* larvae than grate 5. *Stylaria lacustris* was more concentrated near the surface in the intake forebay (0.6-m depth) than near the bottom (8.7-m depth) ($p < 0.05$). Total-animals-minus-*Hydra* also showed significant depth effects, with more in samples taken near the surface than at mid-depth or near the bottom (Table 10).

Thus, significant heterogeneity occurred in the intake forebay, but the direction and types of effects were not consistent across different taxa of zoobenthos. In particular, it was surprising that larger numbers of animals occurred near the surface. Flow patterns in the intake forebay are undoubtedly complex, and may account for some of the significant effects through centrifugal or centripetal forces generated by changes in flow direction. It seems more likely, however, that chance patches of higher faunal concentrations were passing through the plant at times when a given depth was being sampled. The three depths were sampled consecutively, not simultaneously. Grate effects for *Chironomus* are less readily

TABLE 10. Results of Student-Newman-Keuls multiple range tests for significant effects of rates and depths on concentrations of entrained zoobenthos ("x", in number/m³) in August 1974. Lines beneath connect means which were not significantly different. (ln = log to the base "e").

- 1 Total-animals-minus-*Hydra* (both day and night), Grate effects
(0.10>p>0.05)

	Grate number		
	6	7	8
$\bar{y} = \frac{\ln(x + 1)}{\ln(x + 1)}$	1.51	1.32	1.06
antiln $\bar{y} - 1$	3.53	2.74	1.89

- 2 Total-animals-minus-*Hydra* (both day and night), Depth effects
(p<0.05)

	Depth (m)		
	0.6	5.6	8.7
$\bar{y} = \frac{\ln(x + 1)}{\ln(x + 1)}$	1.58	1.18	1.12
antiln $\bar{y} - 1$	3.85	2.25	2.06

- 3 *Chironomus fluviatilis*-form (night only), Grate effects
(p<0.01)

	Grate number		
	7	6	5
$\bar{y} = \frac{\ln(x + 1)}{\ln(x + 1)}$	1.20	0.95	0.29
antiln $\bar{y} - 1$	2.32	1.59	0.34

- 4 *Stylaria lacustris* (night only), Depth effects
(0.10>p>0.05)

	Depth (m)		
	0.6	5.6	8.7
$\bar{y} = \frac{\ln(x + 1)}{\ln(x + 1)}$	0.83	0.52	0.29
antiln $\bar{y} - 1$	1.29	0.68	0.34

explained, since three sampling pumps were used to sample all three grate locations at the same times. Perhaps centrifugal forces created as the flow through the forebay turned northward between intakes and circulating water pumps (Fig. 30) selectively concentrated the relatively heavy-bodied *Chironomus* larvae on the outer rim (southeastern edge) of the flow.

Concentrations of zoobenthos in entrainment samples varied widely from one sampling date to another (Table 11). *Chironomus fluviatilis*-form was abundant in May, but rare in July, while concentrations of *Nais pardalis* and *Stylaria lacustris* tended to increase through the summer. Populations of these two naidids also increased in the lake through the summer (see Seasonal Abundance of Common Naididae Species, 0-16 m). *Chironomus fluviatilis*-form appeared to emerge in late spring, and pre-emergence activity of fourth instar larvae (Dugdale 1955) probably elevated entrainment concentrations in May.

November entrainment collections were made at three grates, but were not replicated. The long time period of collection gives a more complete estimate of day/night contrasts than the brief sampling times of earlier studies (Table 9). Total-animals-minus-*Hydra* averaged $3.52/\text{m}^3$ in the day and $15.8/\text{m}^3$ at night (Student's t-test, $p < 0.01$). *Chironomus fluviatilis*-form was the most abundant taxon, followed by Tubificidae and the naidid *Nais pardalis*. Among common taxa only *Hydra* and *Pontoporeia* were more numerous in day than night samples. Perhaps because of a storm which passed over the Cook Plant during entrainment collections, a greater variety and larger numbers of zoobenthos were obtained in November than in earlier studies. The trichopteran *Hydropsyche*, the amphipod *Hyaella* and the isopod *Aseellus* were unusual taxa for entrainment sampling, but were relatively common in November ($0.04\text{--}0.5/\text{m}^3$). The abundance of Tubificidae ($3.3/\text{m}^3$ at night) was somewhat surprising. Whether these worms swam off bottom or were stirred into the water column by the storm, these results suggest a mechanism by which tubificids could have dispersed throughout the Great Lakes.

Pontoporeia and *Mysis* have been of great concern in entrainment studies, due to their well-known, nocturnal swimming habits and their importance as fish forage organisms (Table 12). In each month, considering only the volume pumped from the intake forebay at night, concentrations of these

TABLE 11. Means of zoobenthos across all depths and replicates for each sampled grate in the intake forebay of the Cook Plant, day and night. Units are number per cubic meter.

Month	Taxon	Time	Grate (MTR 1-)			
			2	5	6	7
May	<i>Chironomus fluviatilis</i> -form	Day	0.12	0.12		
		Night	4.41	2.58		
	<i>Hydra americana</i>	Day	0.84	1.00		
		Night	0.69	0.76		
July	<i>Chironomus fluviatilis</i> -form	Day		0		0.05
		Night		0.05		0.10
	<i>Paracladopelma tylus</i>	Day		0.31		0.11
		Night		0		0
	<i>Nais pardalis</i>	Day		0.32		0.53
		Night		0.23		0.05
	<i>Stylaria lacustris</i>	Day		0.05		0.21
		Night		0.05		0.28
	Total-minus- <i>Hydra</i>	Day		1.39		1.49
		Night		0.49		0.80
	<i>Hydra americana</i>	Day		1.02		0.79
		Night		0.11		0.11
August	<i>Chironomus</i> - <i>fluviatilis</i> -form	Day		0	0	0
		Night		0.39	1.69	2.47
	<i>Paracladopelma tylus</i>	Day		0.09	0	0.10
		Night		0.25	1.16	0.61
	<i>Nais pardalis</i>	Day		0	0	0.10
		Night		1.14	2.20	1.13
	<i>Stylaria lacustris</i>	Day		0	0	0
		Night		1.35	1.00	0.31
	<i>Gammarus fasciatus</i>	Day		0	0	0.10
		Night		0.70	0.66	0.60
	Total-minus- <i>Hydra</i>	Day		0.52	2.14	0.69
		Night		5.44	8.90	7.78
	<i>Hydra americana</i>	Day		62.2	20.4	12.4
		Night		72.7	29.5	19.2

TABLE 12. *Pontoporeia affinis* and *Mysis relicta* in entrainment samples, 1974. Only nocturnal sampling volumes are given but all specimens of these specimens collected day or night are listed.

Month	<i>Pontoporeia</i>	<i>Mysis</i>	Volume sampled (m ³)
May	2	0	30
July	1	3	45
August	1	0	65
November	8	10	260

larger crustaceans remained near or well below $0.1/\text{m}^3$. These concentrations are lower than those at the Zion Station across the lake (Krueger 1975). Except in November, daytime occurrences of both species were much rarer than night occurrences. As both *Pontoporeia* and *Mysis* move nearer shore in winter (Reynolds and DeGraeve 1972; Santer and Weltner 1904), February 1975 samples were examined to determine concentrations of these macrocrustaceans in the forebay. In 24 hours of pump sampling at grate 6, mid-depth, only 4 *Pontoporeia* and 1 *Mysis* were captured. Data obtained so far do not indicate that significant damage to *Mysis* or *Pontoporeia* populations will occur as a result of entrainment into the Cook Plant.

DRIFTING ZOOBENTHOS

Discovery of an unexpected variety of organisms in early entrainment samples (Mozley 1973a) generated interest in the extent and significance of occurrences of zoobenthos above bottom. Results since the beginning of regular mid-water collections of zoobenthos in 1973 and entrainment sampling in 1974 reenforced the idea that "drifting behavior" (in analogy to the phenomenon of drifting macroinvertebrates in streams) was a regular feature of several species. Since drifting animals are likely to be entrained into the plant's cooling system, the characteristics and possible significance of the phenomenon were investigated further. Analysis of 1973 drift samples was completed (compare Mozley 1974) and the data were supplemented with a July 1974 study of the diurnal periodicity and proportions of benthic populations which occurred in the water column.

Regular monthly samples were taken night and day by low-speed, five-minute tows of a #2 net (0.35-mm mesh openings) at depths approximating those of the intake and discharge structures of the Cook Plant. Stations A, B, C, D, F, G and H (established for fish collections; Jude et al. 1975) were selected for drift studies. Stations A, B and F were located in the surf at a depth of about 1 m, and appeared to accumulate drifting animals and detritus from a broad band of the lake, sustaining them in suspension by steady wave action. There were few or no macroinvertebrates in the benthos at this depth, however. Consequently, analysis of zoobenthos from those stations was discontinued, and more attention was given to 6-m and 9-m stations near the plant and to the south near Warren Dunes State Park.

Several towing procedures were employed at each station in 1973, including limited-depth tows and step-tows. These procedures gave better data on the upper half than the lower half of the water column. Flow meters in the mouths of the nets were calibrated to permit estimation of the volume sampled on each tow; volumes typically averaged 20 m³ per station and visit.

All 1973 macroplankton samples have been analyzed, and graphs presented last year (Mozley 1974) have been expanded to illustrate the results (Fig. 31). Drifting zoobenthos attained higher densities over 9-m depths (stations D and H) than over 6-m depths (stations C and G). In some respects, there was more similarity between stations at the same depth than between adjacent 6 m and 9 m stations. The two 6-m stations had a peak in abundance in June, when few zoobenthos occurred in the drift at 9-m stations. In July, 9-m stations reached the yearly maximum, but 6-m stations had fewer zoobenthos than in the preceding month. All stations exhibited a second peak in abundance in September, but the peak was less prominent at 9-m stations.

Day-night differences were pronounced, with a relatively constant, low density of drifting zoobenthos in the day, but higher, seasonally varying densities at night. The highest density during 1973 occurred at night at station H: 34/m³ or a calculated total of 306/m² of lake surface in the 9 m of water overlying the bottom there. In the same month (July) benthic abundances were estimated to be 5300-6600/m² from grab samples taken in 1973 at station H.

Chironomid larvae and naiddid oligochaetes comprised most of the drifting zoobenthos, but half of all species recorded from Cook Plant benthic surveys have been found at least once in macroplankton samples. Tubificidae and *Hydra* were present above bottom regularly, but in low numbers. All species of Acari, Trichoptera and larger Crustacea were collected above bottom, but Pelecypoda were not. Certain species of chironomids and naiddids were more prominent in macroplankton samples than they were in benthic samples, or were found only above bottom, while other species in these groups were rarely collected in net tows. As in entrainment samples, the most common drifting macroinvertebrates were *Chironomus fluviatilis*-form, *Paracladopelma tylus*, *Nais pardalis* and *Stylaria lacustris*.

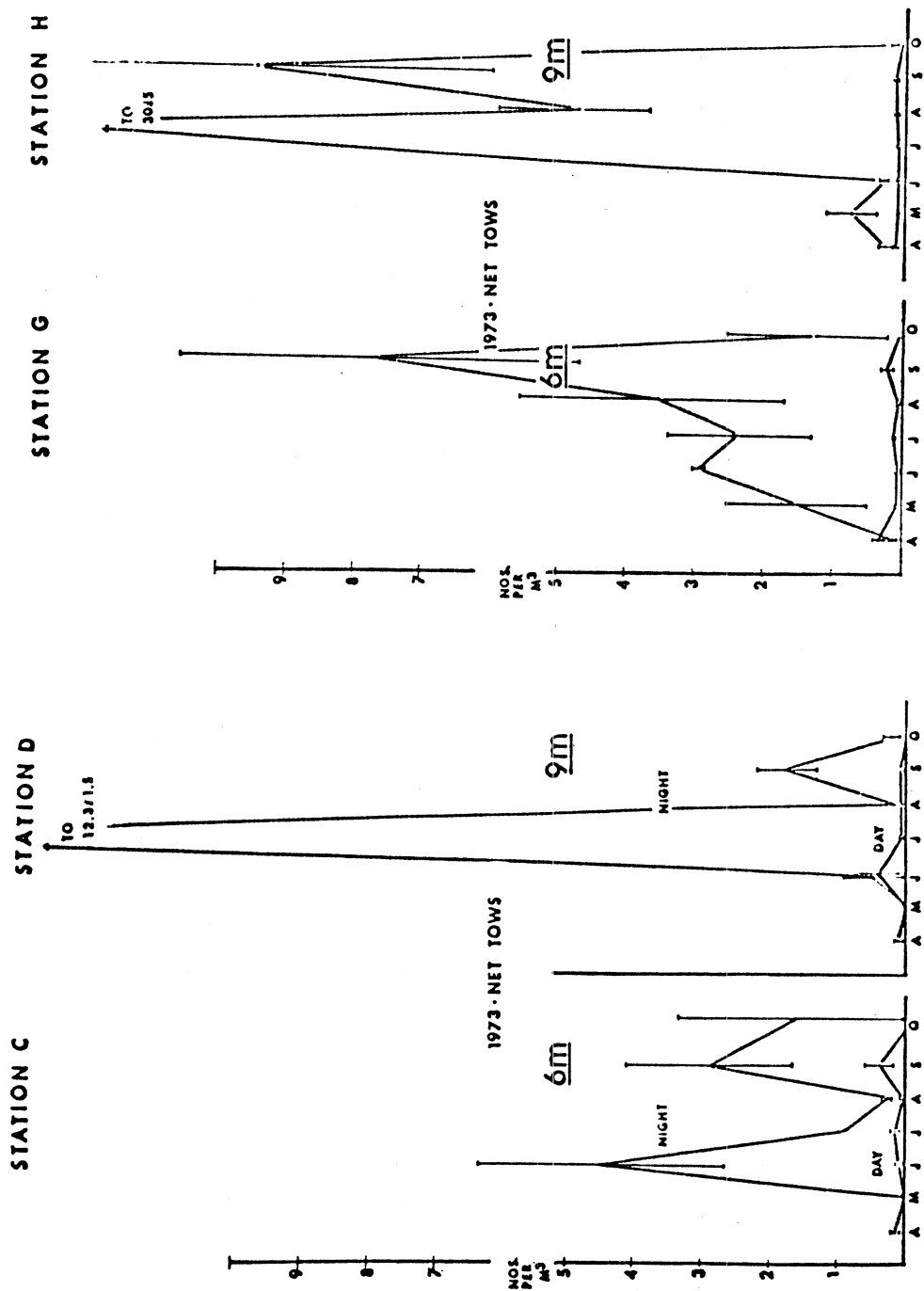


FIG. 31. Monthly station means and standard errors for total zoobenthos in macroplankton samples at 4 stations in 1973.

A special study of benthic and drifting abundances of zoobenthos was undertaken to compare the two groups directly, using the same screen sizes (0.15 mm) to strain both samples, and to determine the diurnal periodicity of drift. Previously, direct comparisons were hindered by differences in mesh sizes and station locations of benthic and macroplanktonic collections. The present author and M. W. Wiley sampled drifting and non-drifting zoobenthos at stations C (6 m) and D (9 m) on July 23-24, 1974. One further dimension was also incorporated into that study--that of distance above bottom. Tows were made 1 m below the surface and 1 m above bottom at each station, in replicate, at four times of day: early afternoon, dusk, midnight and mid-morning.

Approximately twice as many zoobenthos were collected in the drift near bottom than near the surface at the 6-m station, while four times as many were taken near the bottom as near the surface at the 9-m station (Fig. 32). *Nais pardalis* and *Chironomus fluviatilis*-form were better represented near the surface than other species.

Peak drift among the four sampling periods occurred at night for almost all taxa (Fig. 33). Chironomid pupae, however, continued to increase in density through the mid-morning tows (not shown in Fig. 33 or included in totals or Chironomidae). Naidids showed less diurnal periodicity than other taxa in this study. Analysis of variance indicated that both the depth of towing effects and day/night effects were significant ($p < 0.01$) for densities of drifting zoobenthos.

Densities of zoobenthos in all taxa combined were approximately the same at 6 and 9 m, but chironomids were less abundant and turbellarians were more abundant in the drift at 9 m (Fig. 33).

Benthic collections within the special study, reported in "The Smaller Zoobenthos" below, enabled estimation of the percentage of total zoobenthos which drifted. *Paracladopelma tylus* had the highest percentage of its population above bottom among benthic macroinvertebrate taxa, about 2.1% at the 9-m station. This was equivalent to 0.6 larvae/m³, and occurred in near-bottom tows of the midnight sampling period. Proportions for *Paracladopelma* and other taxa are given in Table 13. Much higher densities have been observed in regular macroplankton collections than occurred in the special study, and it is likely that substantially larger proportions of

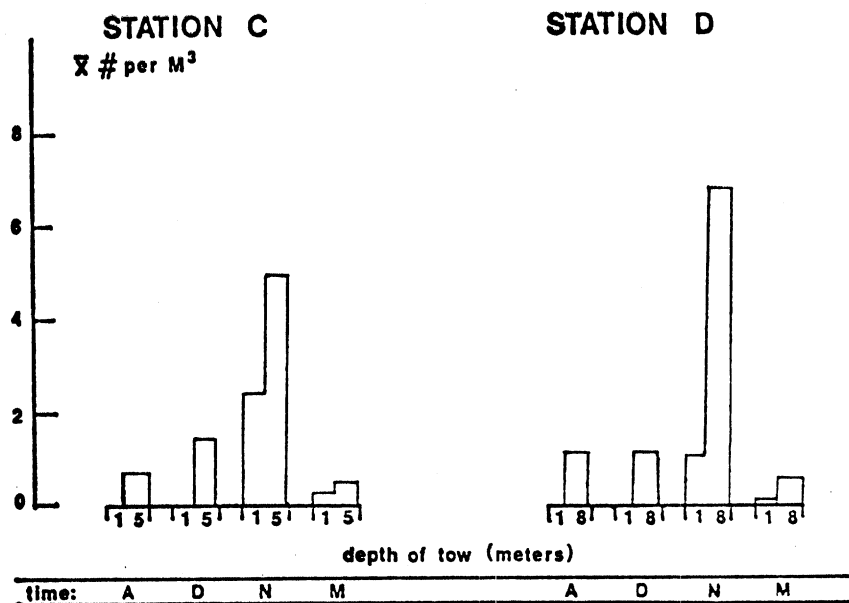


FIG. 32. Periodicity and vertical distribution of drifting zoobenthos at station C (6 m) and station D (9 m) in July 1974. A = afternoon, D = dusk, N = midnight, M = midmorning.

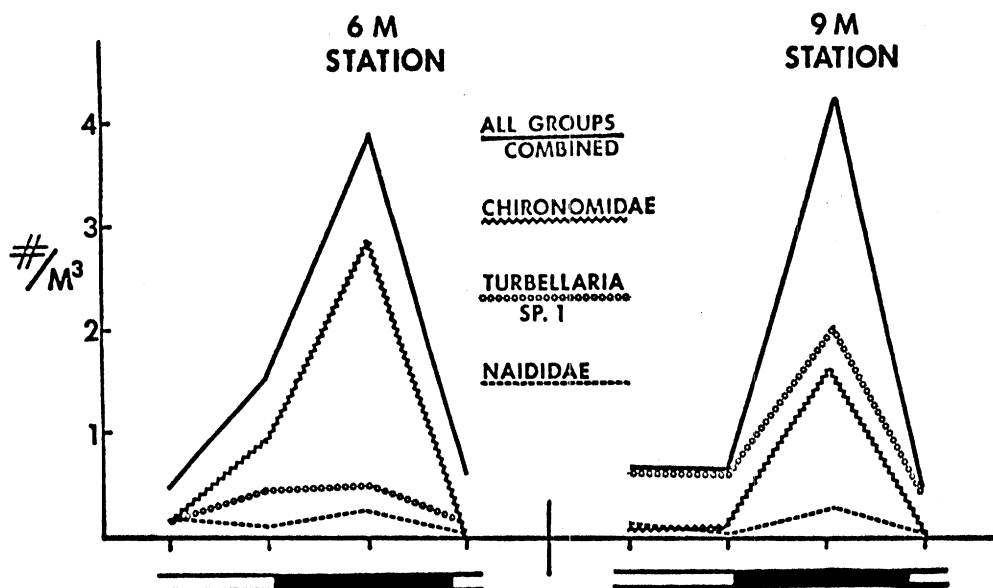


FIG. 33. Diurnal periodicity of drifting zoobenthos by major taxa at two stations. Marks on the abscissa show sampling times. Night is indicated by a dark band.

zoobenthos drift on some nights (Table 13). Proportions of benthic populations which drifted in the special study were comparable to those known to drift in streams (0.001-0.5%; Waters 1972). In streams, drift plays an important role in recolonization of disturbed habitats. Since currents of 1-10 cm/sec are almost continually flowing in nearshore areas of Lake Michigan (Hydrocon, Inc. 1975), drifting zoobenthos may be dispersed over distances as great as several kilometers in a single night.

Some aspects of drift data from the vicinity of the Cook Plant suggest that this behavior plays an important role in maintaining benthic populations at shallow depths. Composition of the drift at both station C and station D resembled benthic species composition at station C (6 m, Table 14). In particular, *Paracladopelma tylus* was more abundant in nocturnal drift at the 9-m station (D), but more abundant in the benthos at 6 m. Gradual onshore-offshore mixing and selective settling (reduced tendency to drift) in shallower habitats could result in net transport of these species nearer shore. Catastrophic disturbance of the shallow bottom by storms would counter this tendency by displacing zoobenthos lakeward or destroying shallow-water animals. Recovery from periodic disturbances would be provided by drifting behavior. This should cause the shallowest zoobenthic assemblages to be composed largely or exclusively of species with a pronounced tendency to drift, which in fact seems to be the case.

A similar pattern of greater drifting tendency in species which occur primarily in shallower habitats was found by Mundie (1959). Species which inhabited 5-m depths in Lac la Ronge, Saskatchewan were collected above bottom in greater numbers than species which occurred mainly in deeper parts of the lake, with the exception of *Pontoporeia* and *Mysis*. Hiltunen (1969b) has also observed drifting zoobenthos in a Great Lake and concluded that they were composed primarily of shallow-water species.

The potential impact of drifting behavior, and removal of drifting animals by mechanical means, is indicated by Hudson (1971). In his study, up to 8% of the entire population of a species of *Procladius* in Lewis and Clark Reservoir (Diptera, Chironomidae) was lost in a single night through the sluice gates of the dam. Maximum densities observed by Hudson for a number of chironomid species in the sluiceway ranged as high as 11/m³, approximately the same as observed for *Chironomus fluviatilis*-form larvae

TABLE 13. Maximum percentages of benthic populations, and maximum densities (No./m³) of total zoobenthos and prominent species which occurred in the drift in July 1974, with comparative maximum densities from regular macroplankton collections in other months at 6-m and 9-m stations.

Taxon	July 1974		July 1973 No./m ³	Aug. 1974 No./m ³	Overall maximum No./m ³
	%	No./m ³			
<i>Turbellaria</i> sp. 1	0.7	2.1	--	--	2.1
<i>Nais pardalis</i>	0.03	0.06	4.7	1.5	4.7
<i>Stylaria lacustris</i>	0.01	0.06	0.6	0.9	10.1
<i>Chironomus</i> fluviatilis-form	0.5	0.5	4.8	1.5	15.9
<i>Paracladopelma tylus</i>	2.1	0.6	0.03	0.7	1.6
Total zoobenthos	0.1	3.0	12.3	7.4	33.0

TABLE 14. Benthic macroinvertebrates present in plankton samples July 23-24, 1975.

Taxon	Depth	Taxon	Depth
<i>Hydra americana</i>	6m	<i>Cladotanytarsus</i> sp. 2	6m
<i>Nais barbata</i>	9m	<i>Monodiamesa tuberculata</i>	6m, 9m
<i>Nais pardalis</i>	6m, 9m	<i>Paracladopelma</i> cf. <i>nais</i> + <i>obscura</i>	6m
<i>Stylaria lacustris</i>	6m, 9m	<i>Paracladopelma tylus</i>	6m, 9m
<i>Mysis relicta</i>	9m	<i>Potthastia longimanus</i>	6m, 9m
<i>Pontoporeia affinis</i>	9m	<i>Procladius</i> sp.	6m
<i>Hygrobates longipalpis</i>	9m	<i>Psectrocladius simulans</i>	6m
<i>Piona</i> sp.	6m	<i>Turbellaria</i> sp. 1	6m, 9m
<i>Chironomus anthracinus</i> -form	9m		
<i>Chironomus fluviatilis</i> -form	6m, 9m		
<i>Chironomus</i> spp. (instars I and II)	6m, 9m		

in regular macroplankton collections near the Cook Plant (Table 13). Of course, the natural mortality, turnover rate and size of the source area (very large in Lake Michigan) must be considered in order to assess the potential for population damage by removal of drifting individuals.

COMPOSITION AND SEASONAL ABUNDANCES OF OTHER SPECIES

THE SPECIES LIST

The list of zoobenthic species occurring near the Cook Plant continues to increase and change. Many additional species have been added as a result of entrainment studies, particularly in the Decapoda (crayfish) and other taxa which inhabit rock bottoms such as the riprap which has been installed in front of the Cook Plant to protect the bottom from severe erosion. Many new species were encountered in November entrainment samples collected during a storm. Taxonomic skill has advanced considerably for the difficult genus *Pisidium*. Tows of nets to collect materials floating on the surface of the lake have yielded the pupal skins, or casts, of chironomids, as well as some pupae and adult males, which permit more detailed identification of this dipteran family than larval material alone. These advances are embodied in the current species list for Cook Plant zoobenthos (Table 15).

CRAYFISH

The traveling screens of the Cook Plant, belt-like bands of 1.9-cm (3/4-in) mesh which prevent objects large enough to clog the condenser tubes from entering the heat exchangers, entrapped many crayfish in 1974, particularly in summer months. After initial uncertainty on the part of researchers analyzing fish entrapped on the traveling screens, they decided to separate crayfish and transfer them to benthos researchers for identification and sorting. Relatively complete records of entrained crayfish began in mid-July 1974. A total of 2135 crayfish were collected and counted by species, sex, reproductive status and size between July 1974 and March 1975.

Bottom trawling and beach seining for fish, and stomach analysis of

TABLE 15. Benthic macroinvertebrates identified from collections at the Cook Power Plant through 1974.

HYDROIDA

Hydridae

Hydra americana

Clavidae

Cordylophora lacustris

TURBELLARIA

Unknown species 1

Unknown species 3

Gyratricidae

Gyratrix hermaphroditus

NEMATODA

ACANTHOCEPHALA

ECTOPROCTA

OLIGOCHAETA

Aeolosomatidae

Aeolosoma sp.

Enchytraeidae

Lumbriculidae

Stylodrilus heringianus

Naididae

Amphichaeta leydigii

Arcteonais lomondi

Chaetogaster diaphanus

C. diastrophus

C. limmaei

C. setosus

Nais barbata

N. behringi

N. bretscheri

N. elinguis

N. pardalis

N. simplex

Nais spp.

Ophidonais serpentina

Paranais frici

P. littoralis

P. simplex

genus near *Paranais*

Pristina foreli

P. longiseta

P. osborni

P. sima

(OLIGOCHAETA

Naididae)

Piguetiella michiganensis

Slavina appendiculata

Specaria josinae

Stylaria lacustris

Uncinais uncinata

Vejdovskyella comata

V. intermedia

Tubificidae

Aulodrilus americanus

A. pigueti

A. pluriseta

Ilyodrilus templetoni

Limnodrilus angustipenis

L. cervix

L. claparedeianus

L. hoffmeisteri

L. profundicola

L. spiralis

Peloscolex freyi

P. multisetosus

P. superiorenensis

P. variegatus

Potamotheix bedoti

P. moldaviensis

P. vejovskyi

Rhyacodrilus coccineus

Tubifex tubifex

HIRUDINEA

Erpobdellidae

Nepheleopsis obscura

Glossiphoniidae

Glossiphonia complanata

Helobdella elongata

H. stagnalis

ACARI

Hydracarina

Forelia sp.

Hygrobatas longipalpis

Libertia parosa

Piona rotunda

Piona sp.

Sphaericon sp.

TABLE 15 continued.

(ACARI)

Oribatei

Hydrozetes sp.

AMPHIPODA

Gammaridae

*Gammarus fasciatus**Gammarus* sp.

Haustoriidae

Pontoporeia affinis

Talitridae

Hyalella azteca

ISOPODA

Asellidae

Asellus sp.

MYSIDACEA

Mysidae

Mysis relicta

DECAPODA

Astacidae

*Cambarus diogenes**Orconectes propinquus*

CLADOCERA

COPEPODA

PODOCOPA

COLEOPTERA

Dytiscidae

Elmidae

DIPTERA

Ceratopogonidae

Culicoides sp.*Palpomyia* sp.

Chaoboridae

Chaoborus punctipennis

Chironomidae - Chironomini

Chironomus anthracinus-form*C. fluviatilis*-form*Cryptochironomus digitatus**C. fulvus*-gr.

(DIPTERA

Chironomidae - Chironomini)

Cryptochironomus sp. 3genus near *Cryptochironomus**Demicryptochironomus*cf. *vulneratus**Dicrotendipes* cf. *modestus**Glyptotendipes* sp.*Harnischia* cf. *amachaerus*genus near *Harnischia* Agenus near *Harnischia* B*Kiefferulus* sp.*Parachironomus*cf. *abortivus**P. claviger**P. cf. demejerei**Paracladopelma* cf. *nais**P. nereis**P. cf. obscura**P. cf. rollei**P. tylus**Phaenopsectra*

(Phaenopsectra) sp.

Polypedilum fallax-gr.*P. scalaenum**Polypedilum* sp. 2*Pseudochironomus*cf. *fulviventrus*

Chironomidae - Tanytarsini

Cladotanytarsus sp. 2*Cladotanytarsus* sp. 3*Micropsectra* sp. 2*Rheotanytarsus* sp.*Stempellina* cf. *bausei**Tanytarsus* sp. 2*Tanytarsus* sp. 3

Chironomidae - Orthocladiinae

Cricotopus (*Cricotopus*)*annulator**C. (C.) bicinctus**C. (C.) tibialis*-gr.*C. (C.) trifascia*-gr.*C. (C.) vierriensis**C. (Isocladius) sylvestris**Diplocladius* sp.*Eukiefferiella* (?) sp.*Heterotrissocladius*cf. *grimshawi*

TABLE 15 continued.

(DIPTERA

Chironomidae - Orthoclaadiinae)

H. cf. subpilosus
Microcricotopus bicolor
Microcricotopus sp.
Orthocladus sp.
Paracricotopus sp.
Psectrocladius simulans

Chironomidae - Diamesinae

Monodiamesa tuberculata
Potthastia longimanus

Chironomidae - Tanypodinae

Procladius spp.
Thienemannimyia-gr. sp.

Simuliidae

Simulium sp.

Tipulidae

Tipula sp.

EPHEMEROPTERA

Baetidae

Baetis sp.

Caenidae

Caenis sp.
Tricorhythodes sp.

Heptageniidae

Stenonema

HEMIPTERA

Belostomatidae

Lethocerus sp.

Corixidae

Pleidae

ODONATA

Coenagrionidae

Nehellena sp.

Gomphidae

Gomphus sp.

TRICHOPTERA

Hydropsychidae

Hydropsyche sp.

Hydroptilidae

Hydroptila sp.

(TRICHOPTERA)

Leptoceridae

GASTROPODA

Hydrobiidae

Ammicola spp.
Bithynia tentaculata
Somatogyrus subglobosus

Lymnaeidae

Lymnaea spp.

Physidae

Physa integra

Valvatidae

Valvata sincera

Pelecypoda

Sphaeriidae

Pisidium adamsi
P. amnicum
P. casertanum
P. compressum
P. conventus
P. fallax
P. ferrugineum
P. henslowianum
P. lilljeborgi
P. nitidum
P. obtusale
P. subtruncatum
P. variabile
P. walkeri
Sphaerium corneum
S. nitidum
S. securis
S. striatinum
S. transversum

large salmonid fish, have added a few records of crayfish (20 specimens). The small number in such collections suggests that the largest populations near the Cook Plant occur on the riprap near the intake structure. Not surprisingly, the finer-meshed nets used to collect fish in the lake retrieved smaller crayfish much more effectively than the traveling screens. Other sources yielded crayfish shorter than 3 cm (rostrum to tip of uropods) in the proportion of 1 in 4, but impinged specimens from the traveling screens included only a single individual as small as that. The smallest size class which contributed more than 10% to the total number of crayfish was the 6-cm (5.0-5.9 cm) group.

Except for a single *Orconectes immunis*, all mature male crayfish impinged on the traveling screens were *O. propinquus*, as were all females which were examined in detail. A single *Cambarus diogenes* was found in a beach seine collection, but all other crayfish collected outside the plant (when identifiable) proved to be *Orconectes propinquus*, as well. Identifications were based on keys and descriptions in Crocker and Barr (1968) and Hobbs (1972). The only deviation of Cook Plant specimens from the descriptions was in their large size (up to 7.5 cm).

A rough estimate of the number of larger crayfish entrained per day was derived from periods when continuous information was available over several days. The total number of crayfish was divided by number of days from 11 July to 19 September 1974, to obtain an average of 31.2 crayfish per day from impingement samples. Numbers per day appeared to be higher in July than later in autumn or in midwinter (a few February and March samples from 1975). The same pattern was observed at the Palisades Nuclear Plant (Consumers Power Company 1975).

Data on reproductive condition gave no indication of major changes in population status from July 1974 to March 1975. The proportion of Form II (reproductively inactive) males was consistently greater than that of Form I (reproductively active) males in early and middle July, but thereafter proportions of the two forms remained approximately equal. Only one female was captured in berry (24 July 1974). The main breeding period probably precedes July.

THE ROCK HABITAT

Divers collected exploratory, non-quantitative samples from the Cook

Plant riprap by scraping algal material and associated detritus into jars. A sample taken on 15 August 1973 yielded 41 *Psectrocladius simulans*, 4 *Cricotopus* spp., 3 *Nais pardalis* and 16 *Gammarus fasciatus*. While each of these species has been collected in benthic surveys from sandy or silty habitats, they were never dominant, and *Gammarus* especially was extremely rare in grab-sampler collections. Macroplankton and entrainment samples, on the other hand, have contained these species regularly. The estimated densities of *Gammarus* in entrainment samples generally exceed estimates for *Pontoporeia*, probably because the more active *Gammarus* occurs abundantly just adjacent to the intake structure.

PISIDIUM SPECIES

All published species data on the genus *Pisidium* for the Great Lakes are attributable to two researchers, the late Rev. H. B. Herrington and Dr. W. H. Heard. These men published several detailed reports and produced an extensive collection of Sphaeriidae (University of Michigan Museum of Zoology).

With considerable help from Prof. J. B. Burch and other museum personnel, Mr. T. W. Zdeba and the author have managed to overcome the taxonomic difficulties presented by this genus. It proved necessary to open and clean the shells in a laboratory sonicator before many species could be positively identified, for the most reliable characters are the shapes of the cardinal hinge teeth. Data on species composition and depth distribution of *Pisidium* have been obtained so far, for the November 1970 survey and the central (D) and south reference (S) regions of the Cook survey area in July 1973. D region data are less complete, since some *P. nitidum* were misidentified as *P. subtruncatum* and the error was discovered only after the material from several stations had been mixed together. There has probably been some confusion between *P. variabile* and weakly marked, young specimens of *P. lilljeborgi* also. Finally, several specimens in depth zone D1 were damaged in the early tests of sonic cleaning or storage in insufficiently buffered formalin, and could not be identified. S region data are free of these defects. November samples were used to develop identification skills, and records for stations were not kept separately. Species composition was essentially the same as in July 1973.

These data offer a new, detailed and almost unique view of inshore *Pisidium* composition in Lake Michigan.

In the two tables (Tables 16 and 17), totals in the last column exceed sums of the species listed separately. The difference is due to immature or damaged specimens which could not be identified, plus several rare species (*P. adamsi*, *P. amnicum*, *P. compressum*, *P. fallax*, *P. ferrugineum*, *P. obtusale* and *P. walkeri*).

Numbers of *Pisidium* increased 3.5-fold from zone D1 to the next deeper zone (D2) but relative abundances of the species were quite similar (Table 16). *P. lilljeborgi* contributed about 2/3 of the total identifiable specimens. Some of the uncertain, immature specimens were probably members of this species. *P. casertanum* increased its contribution from 7% to 15% between zone D1 and zone D2, while the percentage due to *P. lilljeborgi* and rare species declined. In zone D3, *Pisidium* composition was different. The two most numerous species were *P. conventus* and *P. nitidum*, which together made up 98% of all identifiable specimens. By chance, there was a 12-m difference in depth between the deepest station in zone D2 and the shallowest in zone D3 on that survey, and this difference spanned the siltation boundary in the D region. All D2 stations had sandy sediments, but all D3 stations had silty or gelatinous, clayey sediments.

From zone 0, where *Pisidium* was not represented, to zone D2 each species increased both in abundance and frequency of occurrence in replicate casts of the grab. The two dominant species were present in every cast (100% frequency) in zone D3, but no other species occurred in more than 1/3 of all casts in that zone.

In the south region (Table 17), *Pisidium* composition and distribution differed in several minor respects. Station S210 yielded a *Pisidium* assemblage intermediate between the *P. lilljeborgi*- and *P. conventus*-dominated groups, and station S111 had a larger proportion of *P. nitidum* than other stations at comparable depths. Another species, *P. ferrugineum*, occurred only in the south region. Otherwise, species composition was similar in the two regions. The two taxonomically aberrant stations were set apart from other stations at comparable depths by sediment texture, also. Silt was the predominant grain size, in contrast to sandy sediments elsewhere in the same zones. At S111, *P. lilljeborgi* was unusually numerous,

TABLE 16. *Pisidium* species (#/m²) in the D region, July 1973. Depth-zone 0 stations yielded no *Pisidium*. Station means (3 casts of the grab), zonal means (\bar{x}) with standard errors (SE), and percentage of all identifiable specimens (%) are given for each species. Zonal means and standard errors are also given for total *Pisidium*, including miscellaneous, rare species and those which were unidentifiable young or damaged specimens.

Station/ Zone	Depth (m)	<i>Pisidium</i> species (names abbreviated)								Total
		<i>lillj.</i>	<i>casar.</i>	<i>varia.</i>	<i>hensl.</i>	<i>subtr.</i>	<i>conve.</i>	<i>nitid.</i>		
D110	13.7	81	0	61	0	0	0	0	182	
D111	15.2	384	41	41	20	0	0	0	990	
D112	13.1	545	61	20	41	20	0	0	990	
\bar{x}	8.1-16	337	34	41	20	7	0	0	721	
SE		136	18	12	12	7			269	
%		68	7	8	4	1				
D210	18.6	2260	606	323	222	344	61	20	4404	
D211	18.0	424	242	41	81	0	0	0	1050	
D212	18.3	1515	162	41	162	81	20	0	2222	
\bar{x}	16.1-24	1400	337	135	155	142	27	7	2559	
SE		533	137	94	41	104	18	7	983	
%		62	15	6	7	6	1	<1		
D310	30.8	20	81	0	0	20	4444	1474	6282	
D311	35.7	0	0	0	0	0	3818	303	4363	
D312	34.1	61	41	41	0	20	5212	545	6060	
\bar{x}	24.1-40	27	41	14	0	13	4491	774	5568	
SE		18	23	14		7	403	357	606	
%		1	1	<1		<1	84	14		

TABLE 17. *Pisidium* species (#/m²) in the S region, July 1973. Station means (3 casts of the grab in zones 1-3, 5 casts in zone 0), zonal means (\bar{x}) with standard errors (SE), and percentage of all identifiable specimens (%) are given for each species. Zonal means and standard errors are also given for total *Pisidium*, including miscellaneous rare species and those which were unidentifiable young or damaged specimens.

Station/ Zone	Depth (m)	<i>Pisidium</i> species (names abbreviated)							Total
		<i>lillj.</i>	<i>casar.</i>	<i>varia.</i>	<i>hensl.</i>	<i>subtr.*</i>	<i>come.</i>	<i>nitid.</i>	
S010	8.5*	544	0	12	24	24	0	0	725
S011	6.4	181	0	0	0	0	0	0	193
S012	6.1	145	12	0	0	0	0	0	157
S0 \bar{x}	0-8	290	4	4	8	8	0	0	358
SE		127	4	4	8	8			184
%		85	1	1	2	2			
S110	16.8	342	60	0	0	0	0	0	564
S111	14.0	1047	20	101	161	40	0	362	2295
S112	15.2	463	0	0	20	0	0	0	584
S1 \bar{x}	8.1-16	617	27	34	60	13	0	121	1148
SE		218	18	34	51	13		121	574
%		60	3	3	6	1		12	
S210	23.8	342	0	0	0	60	1127	1671	3644
S211	16.8	0	0	0	20	0	0	121	181
S212	15.6	20	0	81	40	0	0	121	362
S2 \bar{x}	16.1-24	121	0	27	20	20	376	638	1396
SE		111		27	12	20	376	517	1125
%		10		2	2	2	30	51	
S310	35.4	0	0	0	0	0	3302	121	3523
S311	29.0	60	0	20	0	121	4349	1872	6765
S312	31.7	101	0	0	0	81	4993	272	5657
S3 \bar{x}	24.1-40	54	0	7	0	67	4215	755	5315
SE		29		7		36	493	560	951
%		1		<1		1	82	15	

*See text.

while at the deeper S210, species with increased abundances were more typical of depth zone 3.

Abundance of *Pisidium* species was less in zone D0 but greater in zone D2 than in the corresponding depth intervals of the south region. The zone 2 distinction would be even larger if the silty station S210 were omitted from comparison. Zone 1 abundance was more comparable between the two regions, partly because variation within both D1 and S1 was large. *Pisidium* numbers were virtually identical between the two regions at depths over 24 m.

Variation among replicates within stations was much higher at depths less than 24 m than in the *P. conventus*-*P. nitidum* assemblage at greater depths. As a rule, the more abundant species had lower coefficients of variation than the less abundant species in depth zones 0-3. For example, coefficients of variation for *P. lilljeborgi* ranged from 24-70%, but those for *P. henslowianum* ranged from 94-173% in zone D2. Similarly, variations in species abundances among stations within zones were larger at depths under 24 m, but relatively small at deeper stations.

Both composition and depth distribution of *Pisidium* species at the Cook Plant were similar to populations elsewhere in Lake Michigan. Although *Pisidium* were identified from only a part of the Cook survey area and a narrow depth range, nearly every species known to occur in the lake was encountered. Only minor differences emerged in relative abundance and depth distribution, principally in abundance of *P. nitidum* (compare Robertson 1967) and *P. henslowianum* (compare Henson and Herrington 1965), both of which appear to be unusually numerous near the Cook Plant. Heard (1962,1963) provides other comparative *Pisidium* data.

Henson and Herrington (1965) compared occurrence and abundance of two common species in the Straits of Mackinac, *P. lilljeborgi* and *P. conventus*, with sediment texture to determine the preferred habitats of each. *P. lilljeborgi* showed a strong preference for sand with less than 10% silt, while *P. conventus* was more adaptable with regard to sediment texture, but was somewhat more likely to occur in silty sand than in coarser or finer materials. At the Cook Plant, *P. lilljeborgi* was also more common in sandy sediments of shallower areas than in silt farther offshore. When a patch of silt accumulated at station S111, however, this species responded

with increased abundance. *P. conventus* was primarily limited by depth, in agreement with Henson and Herrington's (1965) observation that it is a cold-stenothermal form reaching highest abundance just beneath the summer thermocline. In one instance, however (station S210), shallower occurrence of silty sediments appeared to attract this species and its companion form from depth zone 3, *P. nitidum*.

These data demonstrate once again the existence of a major change in species composition of zoobenthos between depth zones 2 and 3 in the Cook survey area, perhaps more clearly for *Pisidium* than other taxa of macro-invertebrates. *Pontoporeia* and *Stylodrilus* increase considerably in abundance from zone 2 to zone 3, and *Heterotrissocladius* cf. *subpilosus* is largely restricted to zone 3, but neither change is as sharply marked as that from a *P. lilljeborgi* assemblage to a *P. conventus*-*P. nitidum* assemblage at or near the 24-m depth contour.

IDENTIFICATION AND NOMENCLATURE OF CHIRONOMIDAE

Chironomid larvae constitute most of the benthic macrofauna near the discharge structure, and can be considered to be representative, important species in the shallowest parts of Lake Michigan. For this reason, and because chironomids appear to be sensitive indicators of water quality and lake eutrophication (Brinkhurst, Hamilton and Herrington 1968), particular emphasis within the Cook Plant benthic survey has been placed on elucidating the taxonomy and life history of species in this family of midgeflies. Larvae collected at depths less than 16 m have been classified by instar (molting stage). Pupal exuviae left behind by emerging adult flies have been collected and identified in June and July 1974 during the period of peak reproductive activity. Many types of larvae have been reared to adult stages under controlled conditions so that positive species identification can be made (species-level taxonomy in the family is based primarily on adult males). Extensive searches have been conducted in the taxonomic literature to unravel complexities of nomenclature, an exercise which is particularly necessary because many of the larval types encountered near the Cook Plant are new or rarely recorded forms for which taxonomy is poorly developed.

One outcome has been association of several larvae or pupae with

adults belonging to the *Harnischia*-complex (Beck and Beck 1969; Saether 1971). Existing definitions within this complex were not adequate to place most species in a known genus, although species names could be determined from Townes' (1945) key to adult males. That is why the species list (Table 15) includes question marks or "gen. nr." qualifiers with generic names. New genera will have to be described for them, or existing concepts broadened to include them.

The life history of Chironomidae has been concisely reviewed by Oliver (1971). Most, if not all species, have four larval instars. The first instar is often planktonic (positively phototactic, Lellak 1968), apparently as an aid to dispersal. The last three instars are essentially benthic but may migrate into overlying water, particularly at night. Larvae molt between each set of instars, and hardened parts of the body enlarge by a factor of 1.5-2.0 at each ecdysis. Adult structures begin to develop in the fourth larval instar, and their presence beneath the clear larval skin enables discrimination of fourth from earlier instars. After locating a fourth instar larva for each species, earlier instars were distinguished by measuring the length of the first antennal segment.

When larvae are about to pupate, primordia of adult wings and legs distend thoracical segments and feeding ceases. This phase is termed the prepupa. Pupae live in the sediments for a few days as development is completed, then swim to the lake surface where they metamorphose and emerge as winged adults. The pupal exuvium is left behind, floating on the surface together with adults which developed imperfectly and pupae which are about to emerge. Collections with nets towed at the surface yield large numbers of such specimens, and provide a qualitative record of recent chironomid maturation.

Another benefit of surface tows lies in the fact that pupae caught just before emergence and individuals which died in the act of eclosion enable pupal and adult stages of the life cycle to be connected, and thus pupal exuviae can be identified to species. Another, more laborious means of associating life stages is to pick individual prepupae from bottom samples and isolate them in vials until they complete metamorphosis. If a male emerges, a definitive series of identifiable adult, with associated larval and pupal exuviae, is obtained. Many species are difficult to rear, however, and many die in the pupal stage. If the pupa

reaches an age of several days before dying, adult structures develop sufficiently to permit positive identification of many species. We have used both these procedures and combinations of them to associate life stages. Currently the identification of females to species is not possible because most chironomid taxonomists have focussed on male reproductive structures.

Results of taxonomic studies are organized around genera or generic complexes for each presents different challenges in identification and nomenclature.

Chironomus is represented by at least three species in Lake Michigan near the Cook Plant. Lenz's (1954) characters of larval blood gills or tubules, have been used to distinguish two larval types, the fluviatilis-form (long, straight tubules tapering to a point) and the anthracinus-form (curled, round-tipped tubules with variable length). Both forms have two pairs of tubules on the ventral side of the eleventh body segment, but neither has caudolateral processes on the tenth segment. Anthracinus-form larvae rear to two or more species (Mozley 1973a), including a species near *C. anthracinus* and one near *C. decorus* (correct name for *C. attenuatus*, Sublette and Sublette 1974). Fluviatilis-form larvae rear to a species near *C. decorus* also. Late in 1974, two distinct size classes of fluviatilis-form, fourth instar larvae with differing depth distribution were noted. Although sexual dimorphism (females larger) is known for *Chironomus* larvae (Hilsenhoff 1966) the magnitude of the difference in this case was larger than would be expected, almost a factor of two in head capsule width. Presumably, there are two species mixed in our data for this form. As species taxonomy in this genus rests ultimately on color-bandings of salivary gland chromosomes in the larvae, we have not attempted further identification of a number of reared males. Larvae will be collected and fixed for study of the cytological characters which appear to be necessary for species identification in this genus.

Many of the known species in the *Harnischia* complex and related genera such as *Cryptochironomus* fall into one of several distinct types. Among these are *Cryptochironomus*, *Demicryptochironomus*, *Harnischia*, *Paracladopelma*, *Parachironomus* and *Leptochironomus*. However, material from the Cook Plant contains a variety of larval, pupal and adult types which conform to none

of these groups. For instance, the species called *Paracladopelma tylus* (Mozley 1974 etc.) falls between definitions of *Harnischia*, *Paracladopelma* and *Cryptochironomus* as the adult, *Cryptotendipes* and other genera as the pupa, and near *Leptochironomus* in the larval stage on the basis of criteria offered by Saether 1971 and Beck and Beck 1969. The larva is similar or identical to the form called *Cryptochironomus borysthenticus* by Černovskii (1949). Solely for convenience, the generic designation *Paracladopelma* will be used for the species *P. tylus* in this report.

Paracladopelma nereis falls clearly into this genus on the basis of adult characters, but the pupa differs from other members of the genus in several respects. Larvae of this species have not been associated with pupae and adults yet, but circumstantial evidence suggests that *P. cf. nais* larvae give rise to *P. nereis* adults. *P. cf. nais* larvae were only recently separated from the category *P. cf. obscura* in Cook Plant data. *P. nereis* adults were confused with *P. tylus* adults in early rearings, and consequently the name *P. nereis* was incorrectly applied to *P. tylus* larval data in Mozley and Garcia (1972), Mozley (1973a,b), and Ayers, Mozley and Stewart (1974). Both species within the type *Paracladopelma cf. obscura* in a broader sense conform to the generic concept for larval stages of *Paracladopelma*.

Gen. nr. *Paracladopelma cf. rolli* was identified from the key of Černovskii (1949). Pupal and adult stages are still unknown for this form. The decision to change Černovskii's generic name *Cryptochironomus* to *Paracladopelma* for *P. rolli* was based mainly on characters of the larval labrum and maxillae. Other characters of the larva do not fit this genus, however. Again, the name *Paracladopelma* will be used as a nearest approximation for the sake of convenience in the present report. Two types of unassociated pupal casts have been collected near the Cook Plant which resemble *Harnischia* (closer to this genus than to other members of the complex, but not completely conforming to the definition). These may correspond to *P. cf. obscura* and *P. cf. rolli* larvae.

Parachironomus cf. demeijerei larvae, identified from Černovskii's key, probably correspond to *Parachironomus claviger* adults and pupae which have been collected near the Cook Plant. Adult stages of the European species *P. demeijerei* and the North American *P. claviger* are

extremely similar (Lehmann 1970; Townes 1945).

Cryptochironomus larvae have been designated by numbers in earlier reports (e.g., Mozley 1974). *Cryptochironomus* sp. 1 larvae are members of an undescribed genus. Pagast (1936) describes a larva, pupa and adult female which he believed to belong in the genus *Cryptochironomus*, and his larval description closely matches *Cryptochironomus* sp. 1 from the Cook Plant. His pupal description matches a male pupa (larval stage unassociated) from the Cook Plant, as well. The adult male characteristics visible in the pupa are clearly not those of *Cryptochironomus*, but more nearly approach genera completely outside the complex. For convenience, the name *Cryptochironomus* will be retained until positively associated larva, pupa and adult male are obtained and the genus can be adequately described.

Cryptochironomus sp. 2 has been reared from larva to male repeatedly, and has proven to comprise two species, *C. digitatus* and a member of the *C. fulvus* complex (Curry 1958; Sublette 1964). *C. digitatus* males were smaller than limits indicated for the species by Townes (1945). *C. fulvus*-form differs from *C. fulvus* in the cephalic tubercles of the pupa. *Cryptochironomus* sp. 3 has not been reared yet. *Cryptochironomus* sp. 4 appears to have been an early instar or unusual specimen of *C. digitatus*.

Polypedilum scalaenum has been identified from associated pupa and adult (Townes 1945), and is presumed to correspond to the larva called by the same name (identified with the key in Roback 1957). *Polypedilum halterale* adults have been collected near the Cook Plant, but the larva is known (Roback 1957), and matches none of the remaining *Polypedilum* larvae at Cook. *P. halterale* may occur in small ponds or lakes near the Lake Michigan shore.

Pupae from the Cook Plant have been reared to *Potthastia longimanus* males. Larvae designated *P. cf. longimanus* are assumed to be this species. The adult male was compared with the description in Serra-Tosio (1968).

Monodiamesa tuberculata pupae with visible, identifiable male genitalia occur at the Cook Plant, confirming the larval identification which had been made with the key by Saether (1973). Another species has been collected as the adult male, one not previously known from North America. *M. nitida* described by Reiss (1968) may have a larva similar to that of *M. tuberculata*, and it is possible that Cook data for the latter form confuse two species.

Psectrocladius simulans has been collected and identified independently in larval, pupal and adult male stages, but has not been reared. An earlier listing of *Psectrocladius* sp. 1 was in error (Mozley 1974); rather, the specimen indicated was a first-instar larva of *P. simulans*.

Microcricotopus bicolor has been identified from an associated set of pupal cast and adult male with characters described by Fittkau and Lehmann (1970). The larva which was listed earlier as *Psectrocladius* sp. 3 (Mozley 1974) has been identified as a *Microcricotopus*, probably *M. bicolor*. A second species of *Microcricotopus* is represented by a pupal cast from the Cook Plant.

Species identification of *Cricotopus*, or identification to the level of subgeneric larval types has become possible with the publication of Hirvenoja's (1973) revision of this and related genera.

A number of *Heterotrissocladius* pupae with well-developed male characteristics have been collected from the Cook Plant, but will not be identified further until Saether's forthcoming key to North American species in this genus is available.

At least two species of *Procladius* have been reared from Cook Plant larvae, but the material has not yet been studied sufficiently to allow confident species identification, or separation of the larvae of the two species.

The *Thienemannimyia*-group of tanypodines (tribe Pentaneurini) is represented by a larva at the Cook Plant. Larvae in the group cannot be identified to genus until pupal or adult stages can be associated with them (Fittkau 1962). "*Conchapelopia* sp." in earlier reports (e.g., Mozley 1974) should accordingly be named *Thienemannimyia*-gr. sp. This name has also been given by Industrial BIO-TEST Laboratories, Inc. (1974) to larvae collected near shore in western Lake Michigan, possibly of the same species as those at the Cook Plant.

The remaining names of Chironomidae (Table 15) are based solely on larval identifications obtained through use of keys by Cernovskii (1949), Roback (1957), etc. Numerical species designations are internal to Great Lakes Research Division collections.

SEASONAL ABUNDANCE OF COMMON CHIRONOMIDAE, 3-16 m

Chironomid species characteristic of depth zone 0 include *Chironomus anthracinus*-form, *Chironomus fluviatilis*-form, *Paracladopelma tylus*, *Cryptochironomus digitatus*, *Cryptochironomus fulvus*-gr. and *Parachironomus* cf. *demeijerei*. In addition, a number of less abundant, more widely distributed chironomids were found frequently in samples from these and slightly greater depths: *Paracladopelma* cf. *rolli*, *Paracladopelma* cf. *obscura* + *P.* cf. *nais*, *Polypedilum scalaenum*, *Cladotanytarsus* sp., *Mono-damesa tuberculata*, *Potthastia longimanus*, *Psectrocladius simulans* and *Procladius* spp. Total Chironomidae in zone 0 ranged from 11% of benthic macroinvertebrates in October 1972, to a high of 88% in September 1972.

Depth distributions and seasonal occurrence of the more common species in the deeper parts of zone 0 and in zone 1 have been determined from monthly samples in 1972 and 1973. Since short surveys (May, June, August, September and November) were restricted to the part of the survey area adjacent to the Cook Plant, only D-region data from seasonal, major surveys were employed for this analysis. Data from representative stations in each of the two zones were averaged and plotted against time. The shallowest part of zone 0 (less than 3 m of depth) was always poor in zoobenthos, while stations in the deeper part sometimes supported large numbers of chironomids or naidids. To reduce the distortion due to variable depths of randomly selected major survey stations, only data from depths of 3-8 m were employed to represent zone 0.

Chironomus fluviatilis-form larvae (Fig. 34) occurred in relatively low densities in spring, and all individuals were in the fourth larval instar. Densities decreased further as these older larvae emerged in late spring, then increased rapidly in following months to maximum yearly levels in fall. Many third instars and earlier stages occurred in mid-summer samples as a result of late spring reproduction. In 1973, a warmer year when many species matured and reproduced earlier than in 1972, an autumn peak was followed by a decline in October, perhaps because of emergence of a second generation in that year. In the absence of direct data on emerging adults, alternate causes of the decreases cannot be rejected (e.g., fish predation).

Chironomus anthracinus-form larvae were more restricted in seasonal

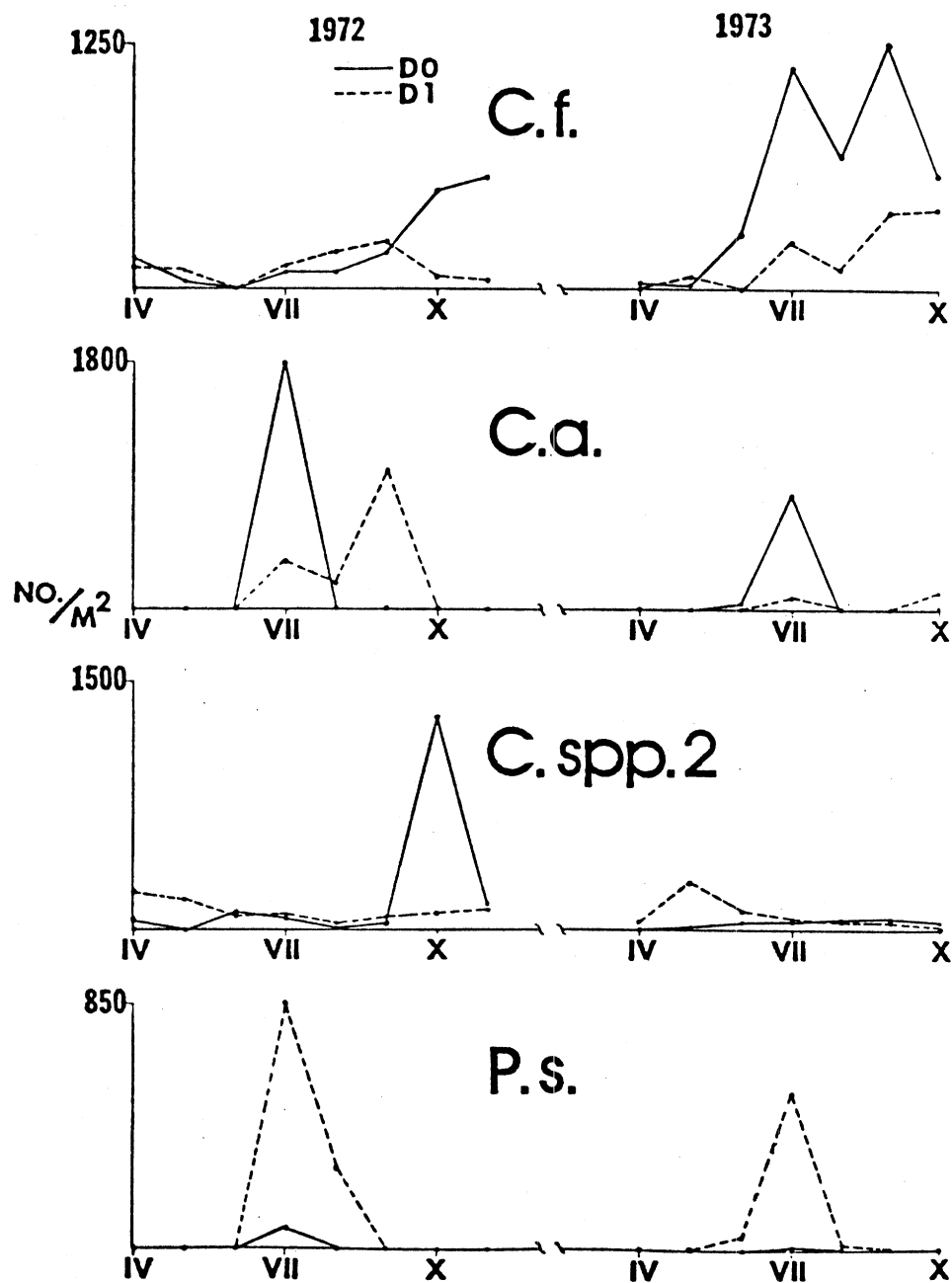


FIG. 34. Seasonal abundance of Chironomidae in zones D0 (3-8 m) and D1 (8.1-16 m) in 1972 and 1973. C.f. = *Chironomus fluviatilis*-form; C.a. = *Chironomus anthracinus*-form, C. spp.2 = *Cryptochironomus digitatus* + *fulvus*-gr., P.s. = *Polypedilum scalaenum*.

occurrence (Fig. 34). Although a few individuals were collected on almost every monthly survey, populations were much larger in July than in other months of both years. No larvae of this type were collected in zone D0 in April or May. Presence of the three last larval instars in July samples suggests that growth occurred rapidly in early summer. Adults apparently emerged in late July, but a new generation did not become established in fall in zone D0. Somewhat deeper (D1), a second generation was evident as higher densities in autumn. In 1972, a September peak density was followed by declines in October and November which may have reflected the emergence of a second generation of adults. In 1973, the autumn peak was poorly developed, with only slightly higher densities in October than in preceding months.

The two common *Cryptochironomus* species, *C. digitatus* and *C. fulvus*-gr., have not been distinguished over a full season of samples, so fluctuation in Fig. 34 may represent complex increases and decreases of both populations. Third and fourth instar larvae of at least one of the two species were present all year near the Cook Plant. Largest densities of both species combined occurred in April and October (zone D0) or November (D1) of 1972, while the maximum did not occur until late spring in 1973. Pupae of *Cryptochironomus* were encountered throughout the year, including one record from the stomach of a fish collected in January.

Depth zone 1 (8.1-16 m) has been characterized by summer occurrence of *Polypedilum scalaenum* (Mozley and Garcia 1972). In both 1972 and 1973, this species was essentially restricted to zone D1 (Fig. 34). Larvae occurred in regular samples only from June to August, with maximum densities in July. Emergence appeared to take place in midsummer, and the species over-wintered as eggs or early instars.

Paracladopelma tylus (Fig. 35), a small species, appeared regularly each summer in large densities in samples from zone D0 as larvae reached the fourth (last) instar. Few individuals were ever encountered in zone D1. Maximum numbers of larvae occurred in June or July samples, but *P. tylus* continued to appear as late as October. There were probably at least two complete generations in both years.

Parachironomus cf. *demeijerei* (Fig. 35) occurred primarily at depths from 3 to 8 m from June to October. Largest densities occurred in August or July. Second and third instars were present in benthic samples just

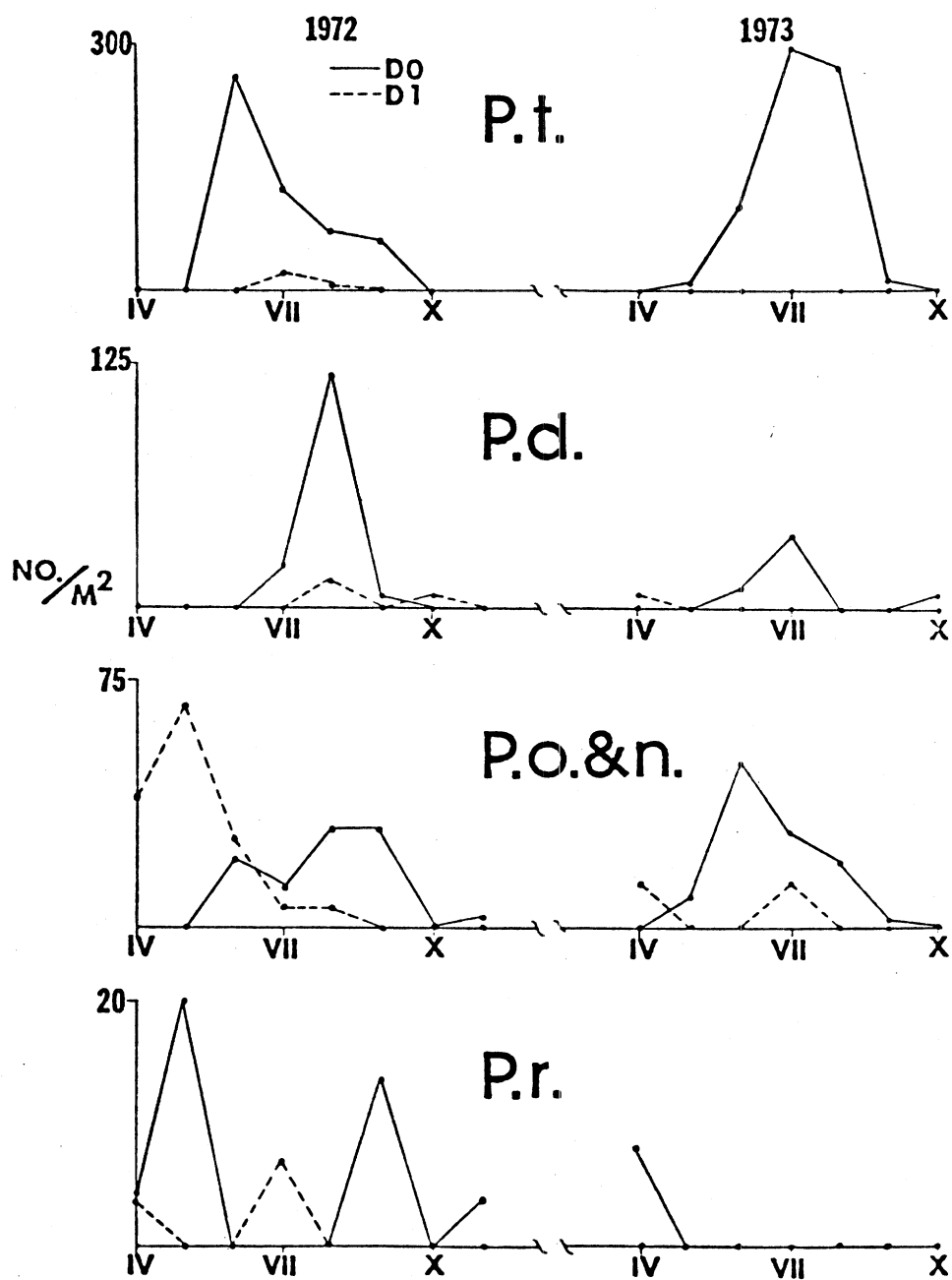


FIG. 35. Seasonal abundance of Chironomidae in zones DO (3-8 m) and D1 (8.1-16 m) in 1972 and 1973. P.t. = *Paracladopelma tylus*; P.d. = *Parachironomus* cf. *demeijerei*; P.o. & n. = *Paracladopelma* cf. *obscura* and *Paracladopelma* cf. *nais*; P.r. = *Paracladopelma* cf. *rollei*.

before the maximum (June and July) and late in autumn, indicating a one-year life cycle with reproduction in midsummer.

The small species designated *Cryptochironomus* sp. 1 (not pictured) did not occur as frequently or as abundantly in summer benthic samples as the other two small species of zone D0 (*Paracladopelma tylus* and *Parachironomus* cf. *demeijerei*). There appeared to be a summer emergence period, but data for this species are questionable because of its extremely small size. All three of these species could escape through the standard 0.5-mm screen, even in the fourth instar.

Paracladopelma larvae in the two species formerly combined as *P.* cf. *obscura* were rarer than forms already presented (Fig. 35, note vertical scale changes). In zone D0, larvae of this type were first encountered in late spring, and increased to an August–September (1972) or a June (1973) maximum. Deeper populations of *Paracladopelma* cf. *obscura* were represented in samples from April to August, reaching largest densities in May 1972. At least one of the two species appeared to emerge in spring (Ayers, Mozley and Stewart 1974). The 1973 advance in the month of maximum abundances in zone D0 suggests that *P.* cf. *obscura* development was accelerated by warmer temperatures, and it is possible that deeper populations emerged prior to the April sampling period in 1973.

Paracladopelma cf. *rolli* occurred sporadically throughout the year in zone D0, with largest densities in spring (Fig. 35). A late spring emergence period may have occurred in both years.

Cladotanytarsus larvae, also small enough to escape readily through benthic sieves used on regular surveys, were present in summer and autumn samples (Fig. 36). A large midsummer maximum was observed in 1973 in zone D0, but not in 1972. In contrast, zone D1 populations were similar in the two years. Few specimens of this species were encountered before July or after August in either year. Consumers Power Company (1975) also recorded locally high abundances of *Cladotanytarsus* in 1973 near the Palisades Nuclear Plant.

Procladius larvae were absent from zone D0 in 1972, but appeared there in July 1973 and increased to a biannual maximum in August (Fig. 36). *Procladius* was represented in samples from zone D1 all year, with peaks in spring and fall. The data may confuse two or more species, so it is not possible to determine reproductive periods from larval abundance data.

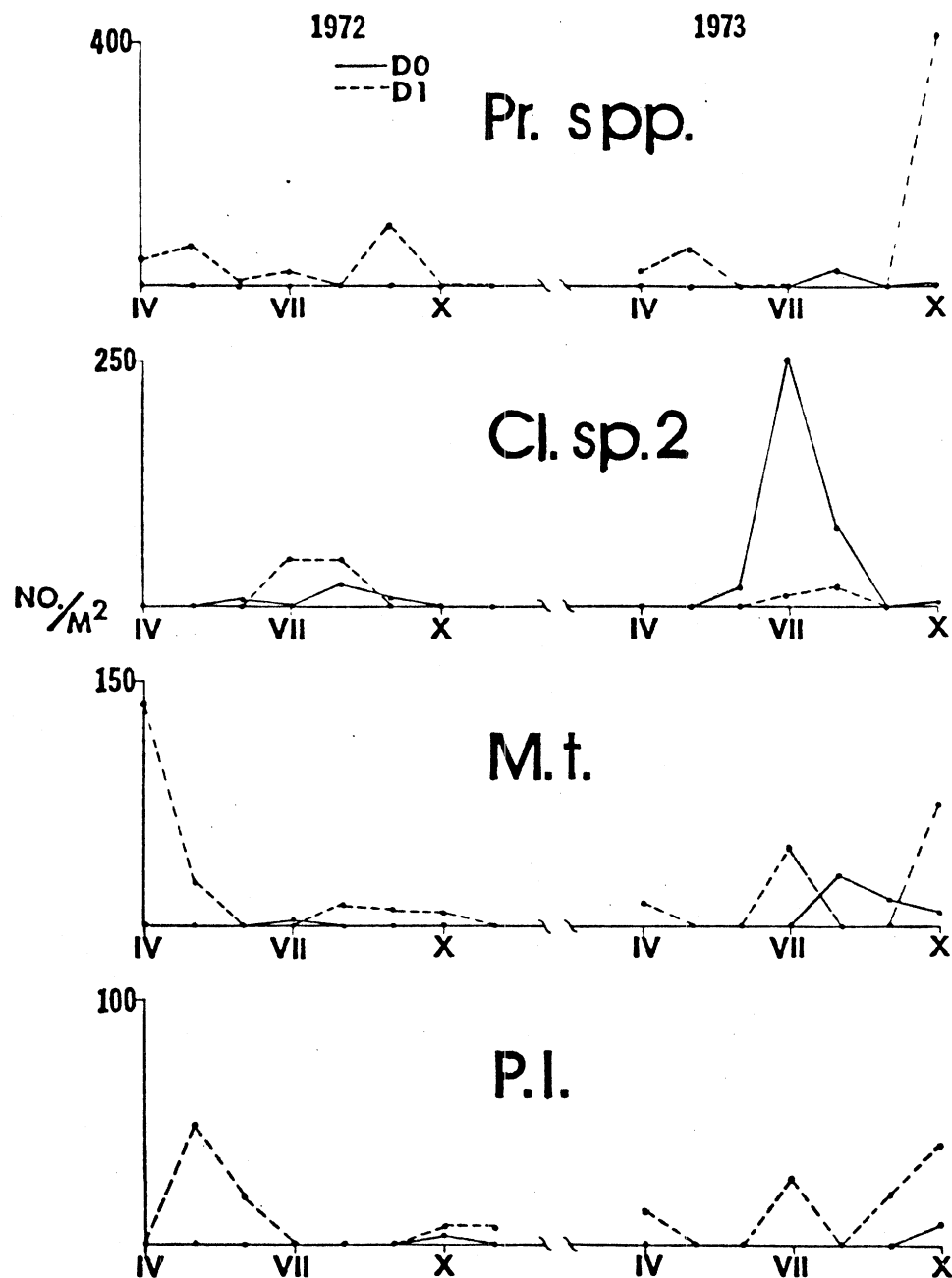


FIG. 36. Seasonal abundance of Chironomidae in zones DO (3-8 m) and D1 (8.1-16 m) in 1972 and 1973. Pr. spp. = *Procladius* spp.; Cl. sp. 2 = *Cladotanytarsus* sp. 2; M.t. = *Monodiamesa tuberculata* P. 1. = *Potthastia longimanus*.

Zone D0 populations of *Monodiamesa tuberculata* also differed strongly between 1972 and 1973, with much higher densities in 1973 (Fig. 36). Zone D1 populations showed less contrast between the two years, and were represented in samples over a longer seasonal period. June minimums in 1972 and 1973 suggested a primary spring emergence, followed by appearance of a small summer generation which emerged in autumn.

Potthastia longimanus was rare in zone D0 (Fig. 36). Abundance patterns in zone D1 were similar to those for the other diamesine, *M. tuberculata*. Summer minimums (July 1972, June 1973) suggested a spring emergence period, which was followed by gradual appearance of the next generation in autumn samples. It is not clear whether there were one or two generations of *Potthastia* each year.

The only Orthoclaadiinae of note in shallower zones was *Psectrocladius simulans* (not pictured). This species was rare most of the year, appearing briefly in July. Large numbers of *P. simulans* on rocks near the Cook Plant (preceding section) indicated that this species occurred in benthic grab samples by accident when individuals drifted from the rock onto sandy bottoms.

The variety of species and emergence periods near the Cook Plant introduced considerable variation into data on chironomid species composition and abundance. A station which in spring supported primarily *Chironomus fluviatilis*-form, *Cryptochironomus* spp., *Monodiamesa tuberculata* and *Paracladopelma* cf. *rolli*, could have a fauna dominated by *Chironomus anthracinus*-form, *Paracladopelma tylus*, *Parachironomus* cf. *demeijerei*, and *Cladotanytarsus* two months later. The many species of abundant, small chironomids which matured in summer elevated estimates of total larval abundance by an order of magnitude or more between June and July. Moreover, several species which had negligible densities in zone D0 in summer 1972 were among the dominants there in 1973 (*Cladotanytarsus*, *Procladius*). Warmer temperatures in 1973 appeared to advance seasonal patterns of reproduction or abundance by one or two months for several species. These findings indicate that natural fluctuations in abundance and composition may exceed a scale which would otherwise be taken as an indication of environmental change.

Spring peaks in larval abundance indicated that June emergers

included *Paracladopelma* cf. *rolli*, *P. tylus* (1972), *Potthastia longimanus*, *Monodiamesa tuberculata* and *Chironomus fluviatilis*-form. Also, *Paracladopelma* cf. *obscura* and *Procladius* larvae were more numerous in spring at least one of the two years depicted in Figs. 33-36. Surface net tows to capture pupal casts of emerging species in June 1974 generally agreed with expectations derived from fluctuations in larval abundance. Over 70% of all casts were from *Paracladopelma tylus*, a surprising result since this species reached the third or early fourth instar in June 1973. *Psectrocladius simulans*, which did not appear in benthic samples before July, contributed another 18%. Casts tentatively identified as *Cryptochironomus* sp. 1 were represented in the surface tow, and *Potthastia* and another *Paracladopelma* species were also present. Surface tows in July also yielded major proportions of *Paracladopelma tylus* (70-93%). Smaller numbers of *Chironomus*, *Paracladopelma* of a third type, *Polypedilum scalaenum*, two species of *Cryptochironomus*, *Psectrocladius simulans*, *Monodiamesa tuberculata*, *Heterotrissocladius* sp. and *Procladius* sp. were also present.

Except for the presence of *Monodiamesa*, July surface tows were similar in chironomid composition to benthic samples. Benthic samples apparently underestimated the large relative abundances of *P. tylus*, however. Early emergences of *P. tylus* indicated by the surface tows confirm speculations based on larval data that this species can go through two or more generations per year. With rapid turnover and abundances much larger than have been estimated in benthic samples (see Methodological Studies), this species may have considerable trophodynamic importance.

SEASONAL ABUNDANCE OF COMMON NAIDIDAE SPECIES, 3-16 m

Naidid oligochaetes, like Chironomidae, were composed of several small species which exhibited summer-autumn maximums at shallow depths in benthic survey data. Although many species of Naididae occur near the Cook Plant, only four or five were at all common. Each of these was probably undersampled by standard benthic screens and the data can only be taken as indicative of their occurrence, and to some degree of relative abundances for different months. Benthic survey estimates indicate that up to 45% of zoobenthos

in zone D0 were Naididae (maximum, August 1973). Autumn proportions of Naididae in total zoobenthos were 12-13%.

Piguetiella michiganensis was approximately equally represented in zones D0 and D1, and occurred in samples all year (Fig. 37). Highest densities occurred between July and October. *Uncinaiis uncinata* was less abundant than *Piguetiella*, but had a similar seasonal pattern of population fluctuations (Fig. 37). These two somewhat larger naidids resembled Tubificidae in their elongated bodies, short, small chaetae and negligible occurrence above bottom in the drift.

Two other species, *Nais pardalis* and *Stylaria lacustris*, were regularly found in the drift, and occurred frequently in tows of the #2 net and entrainment samples (Tables 11 and 13). Both reached large population densities in mid- to late summer, and were rare in samples from months before June (Fig. 37). *Nais pardalis*, however, was present in at least small numbers most of the year in zone D1.

The most periodical of common naidids was *Chaetogaster diaphanus* (Fig. 38). This small, foreshortened predator occurred only in July in zone D0. In zone D1, small numbers were present in samples from July to September or October.

SEASONAL ABUNDANCE OF COMMON TUBIFICIDAE SPECIES, 3-16 m

Tubificid oligochaetes were occasionally an important component of the zoobenthos in deeper parts of zone D0 in 1972 and 1973. They appeared to reach peak densities in July and autumn, when both *Limnodrilus hoffmeisteri* and *Potamothrix moldaviensis* matured (Fig. 39). Most tubificids were immatures without hair chaetae. No other species were found regularly or in large numbers in zone D0.

In zone D1, tubificids dominated the zoobenthos numerically, and *Aulodrilus pluriseta*, *Peloscolex freyi* and immatures with hair chaetae were well represented (Fig. 38). *Aulodrilus pluriseta* did not have a consistent pattern of seasonal abundance. Seasonal fluctuations seemed to result rather from chance occurrence of small, dense patches of this species in one or two replicates at single stations. *Peloscolex freyi* (Fig. 39) was present as identifiable mature stages only from June to August. *Limnodrilus hoffmeisteri* matures appeared earlier in the year

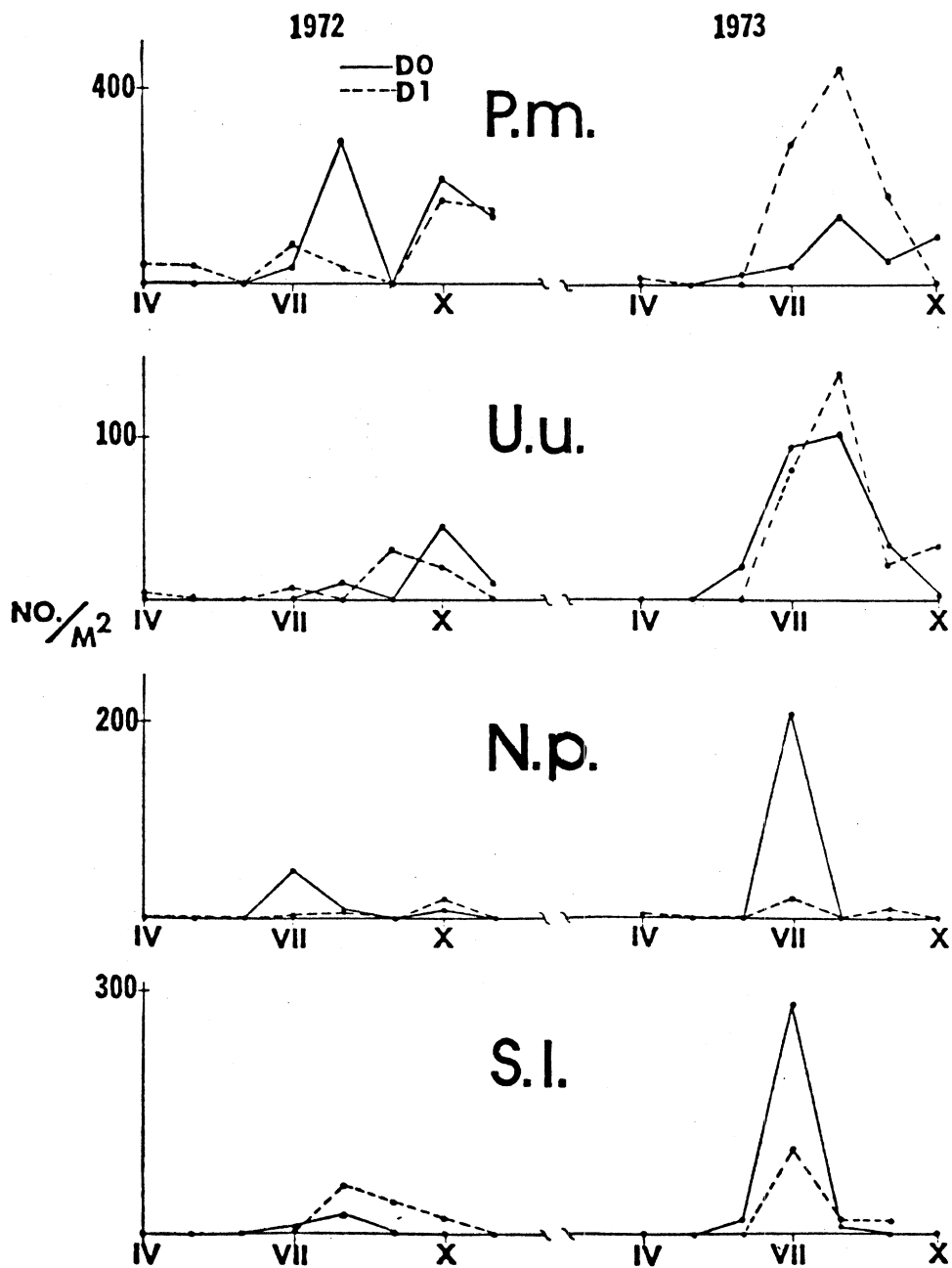


FIG. 37. Seasonal abundance of Naididae in zones D0 (3-8 m) and D1 (8.1-16 m) in 1972 and 1973. P.m. = *Piguetiella michiganensis*; U.u. = *Uncinaiis uncinata*; N.p. = *Nais pardalis*; S.l. = *Stylaria lacustris*.

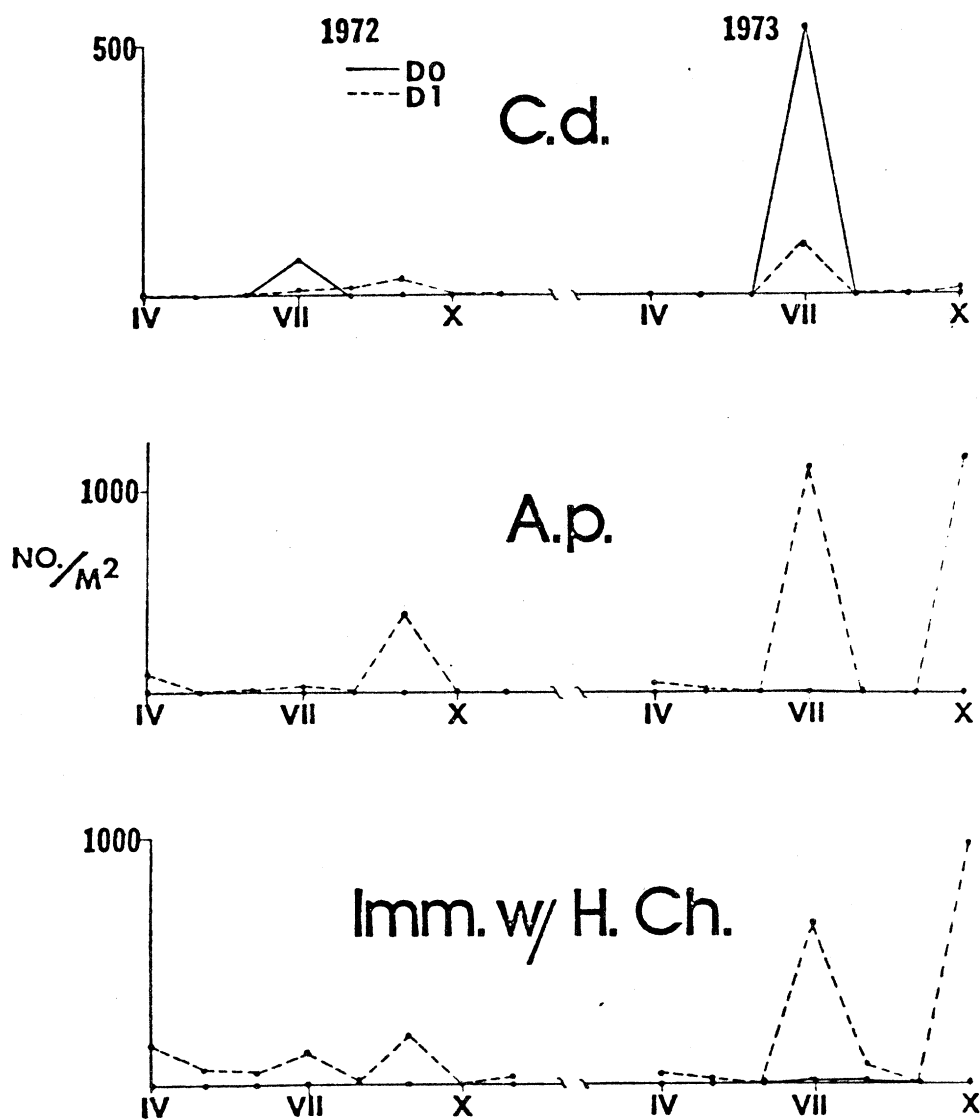


FIG. 38. Seasonal abundance of Naididae and Tubificidae in zones D0 (3-8 m) and D1 (8.1-16 m) in 1972 and 1973. C.d. = *Chaetogaster diaphanus*; A.p. = *Aulodrilus plurisetus*; Imm. w/ H. Ch. = immature Tubificidae with hair chaetae.

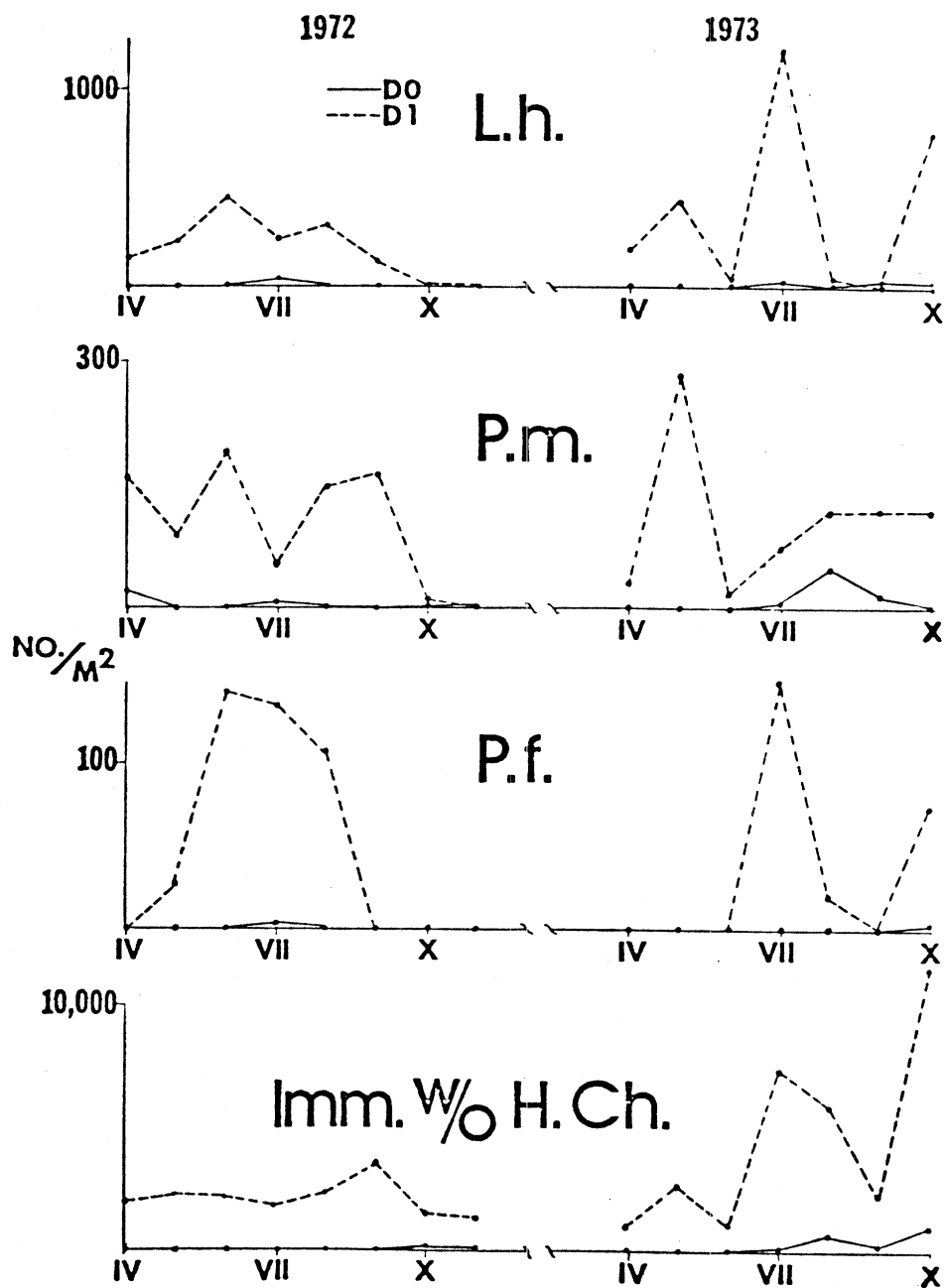


FIG. 39. Seasonal abundance of Tubificidae in zones DO (3-8 m) and D1 (8.1-16 m) in 1972 and 1973. L.h. = *Limnodrilus hoffmeisteri*; P.m. = *Potamothrrix moldaviensis*; P.f. = *Peloscolex freyi*; Imm. w/o H. Ch. = Immature Tubificidae without hair chaetae.

in zone D1 than in zone D0 (Fig. 39). In 1973, the summer peak of mature *L. hoffmeisteri* was followed by a second peak in autumn. Mature *Potamothrix moldaviensis* occurred in zone 1 from July to October, with a maximum in August.

Immature tubificids with hair chaetae, probably young of *Tubifex tubifex*, were present all year in zone D1, with population peaks in summer and fall (Fig. 38). Zone D1 populations were very small relative to deeper populations (Fig. 16) of tubificids.

The foregoing presentation of patterns of seasonal abundance for various species was based on relatively few observations, and sometimes only a single station represented zone D1 (DC-2 on short surveys). Partly because of the small sample size, standard errors were typically 30 to 70% of the means. When a species was represented by only a single individual, standard errors were 100% of the mean. Standard errors were omitted from the graphs to facilitate comparisons of zone means and seasonal trends in a schematic way. Statements of similarity or difference in the last three sections have not been subjected to statistical tests.

METHODOLOGICAL STUDIES

THE SMALLER BENTHOS

Whatever mesh size is selected for benthic sieves, a proportion of animals in the sediments is automatically excluded from analysis (Mozley and Garcia 1972; Jónasson 1955; de Bovée, Soyer and Albert 1974). This is usually acknowledged in descriptions of methods, but few researchers have gone on to determine the quantity or identity of escaping animals. Smaller fauna may be important in detrital decomposition, or as prey for raptorial macroinvertebrates. They also include the younger individuals, sometimes even most of the immature stages, of species which form a significant part of the macroinvertebrate fauna.

Two 1974 studies at the Cook Plant provide preliminary data on smaller zoobenthos. One was a study of the advantage, in terms of the additional species and numbers of animals retained, obtained by decreasing sieve mesh openings from 0.5 to 0.35 mm for regular survey samples. The

other was part of a comparison of densities of zoobenthos occurring in the drift with benthic densities, using a 0.15-mm mesh screen.

THE 0.35-mm SCREEN

Tests of mesh opening diminution were conducted at two stations in the south region in June 1974. The shallower, SDC-7-1 (5.6 m), represented depth zone 0 with its chironomid assemblage, and the deeper, SDC-7-5 (22.3 m), represented the more widespread, *Pontoporeia*-dominated fauna. Material passing through the 0.5-mm screen of the elutriation device was caught in a tub and re-sieved through a 0.35-mm net, and the residue sorted and handled in the same way as ordinary survey samples. Three of the five, full-sized (0.05 m^2) casts of the ponar grab at SDC-7-1 and all three 1/3-sized (0.017 m^2) casts at SDC-7-5 were re-sieved.

Two aspects of the procedure limited the test to preliminary status. First, some of the smaller zoobenthos probably escaped through the 0.5-mm screen which covers the top of the ponar grab as the grab hit bottom or was returned to the ship. Also, a few young individuals and a number of smaller species probably escaped through the 0.35-mm mesh (Jónasson 1955; de Bovée, Soyer and Albert 1974). Thus the test focused on the practical question of ship-board sieving equipment rather than on complete sampling of smaller zoobenthos.

At the shallower station, the two sieves yielded a total of almost 200 animals, more than 80% of which passed through the 0.5-mm mesh (Table 18). While a few rarer species were retained completely on the coarser screen, others, particularly the dominant chironomid larvae, largely or completely escaped it. Three species were found only in the finer fraction, *Parachironomus* cf. *demeijerei*, *Paracladopelma* cf. *obscura* + *nais*, and *Nais pardalis*. Besides *P.* cf. *demeijerei*, two other chironomids which were characteristic of depth zone 0 were retained poorly by the coarser screen, *Chironomus fluviatilis*-form and *Paracladopelma tylus*, with 75% and 85% of larvae passing through onto the 0.35-mm screen, respectively. *Cryptochironomus digitatus* + *fulvus*-gr. (formerly combined as "sp. 2") were completely retained on the 0.5-mm screen, however. *Chironomus* larvae which passed through the coarser screen were with one exception in the second or third larval instar, but many *P. tylus* larvae

TABLE 18. Retention of zoobenthos from a shallower and a deeper station in the Cook survey area by screens with 0.5- and 0.35-mm mesh openings, June 1974.

Station	Species	Number in three grab casts		
		0.5mm	0.35mm	Total
SDC-7-1	<i>Chironomus fluviatilis</i> -form	13	48	61
	<i>Paracladopelma tylus</i> larvae	19	70	89
	<i>Paracladopelma tylus</i> pupae	14	0	14
	<i>Cryptochironomus</i> (dig.+fulv.)	5	0	5
	<i>Cryptochironomus</i> sp. 3	2	6	8
	<i>Parachironomus</i> cf. <i>demeijerei</i>	0	7	7
	<i>Cladotanytarsus</i> sp. 2	2	3	5
	<i>Pontoporeia affinis</i>	3	0	3
	Total count	61	136	197
SDC-7-5	<i>Pontoporeia affinis</i>	253	1	254
	<i>Stylodrilus heringianus</i>	148	30	178
	<i>Limnodrilus hoffmeisteri</i>	11	0	11
	<i>Potamothrix moldaviensis</i>	1	0	1
	<i>Peloscolex freyi</i>	1	0	1
	Immature tubificids without hair chaetae	41	14	55
	Immature tubificids with hair chaetae	4	1	5
	<i>Aulodrilus pluriseta</i>	1	0	1
	<i>Potamothrix vejdoskyi</i>	11	5	16
	<i>Vejdoskyella intermedia</i>	3	13	16
	<i>Pisidium</i> spp.	35	0	35
	<i>Sphaerium</i> spp.	5	0	5
	Chironomidae spp.	3	1	4
	Total count	526	64	590

reaching the finer screen were in the fourth instar and several were prepupae. An intermediate-sized species, *Cryptochironomus* sp. 3, was retained by the coarser screen well in the fourth, but poorly in the third instar. Most third and all second instar larvae in the smaller species (*Paracladopelma*, *Parachironomus* and *Cladotanytarsus* spp.) probably escaped through the 0.35-mm sieve.

Zoobenthic retention by the coarser screen was much more effective for the *Pontoporeia* assemblage. Although a smaller area was sampled, almost 600 animals were retrieved, and 89% of those were retained by the 0.5-mm screen (Table 18). No taxon was added to these replicates by re-sieving through a finer mesh. Only one species, the small naidid *Vejdovskyella intermedia*, was more numerous in the 0.35-mm than in the 0.5-mm screen. Only a single *Pontoporeia* individual escaped the 0.5-mm screen, even though 213 of the 241 individuals were in the smallest size class (less than 3 mm long). All mature Tubificidae and 75% of the immatures, in the group of species which lack hair chaetae and are indistinguishable unless mature, were retained on the coarser mesh. Of unidentifiable immatures with hair chaetae, 80% remained on the 0.5-mm screen. The small tubificid *Potamothrrix vejdoskyi* was less well retained by the coarser screen, while *Stylodrilus* was retained more effectively than tubificids. Overall retention of oligochaetes by the coarser screen was generally effective, but 50% of immature tubificids without hair chaetae reached the 0.35-mm screen in one replicate. Evidently, population size distribution and operator factors can influence effectiveness of tubificid retention by the 0.5-mm screen. All Mollusca (including many small *Pisidium*) were retained on the coarser screen.

THE 0.15-mm SCREEN

A special study of zoobenthic drift was conducted 23-24 July 1974 to enable direct comparison of benthic with planktonic abundance of small Chironomidae, Naididae and other taxa which were not completely retained by the 0.5-mm screens used on regular surveys. For estimates of benthic abundances, 7.2-cm diameter x 45-cm long core liners were inserted 15 cm into the sediments by divers, stoppered at both ends and removed. Two sets of ten core samples were taken, each distributed parallel to the

respective depth contours at a 6-m station (C) and a 9-m station (D) just southwest of the Cook Plant. Cores were spaced in pairs 2.6 m apart with 80 m between adjacent pairs. The entire contents, including water overlying the sediments to a height of 27 cm, were preserved. Later, each sample was repeatedly stirred in a bucket with water from a hose, then decanted through a 0.15-mm screen. Decantation enabled separation of finer and lighter materials (including the benthos) from the predominantly sandy sediments. In the laboratory members of the macroinvertebrate taxa regularly picked and counted in benthic surveys were removed and analyzed. Data from other abundant taxa such as Entomostraca, Nematoda and Ostracoda are reported by Evans (in press).

The smaller mesh size, as expected, increased numerical estimates of zoobenthos several-fold. At 6 m, cores yielded the equivalent of $21,500 \pm 3910$ individuals per m^2 ($\bar{x} \pm S_{\bar{x}}$), and at 9 m, the estimate $42,100 \pm 2650/m^2$. For comparison, July 1974 major survey data from station SDC-.5-1, a station located about 400 m south of the 6-m coring station and having the same depth, provided an estimate of $3500/m^2$ (Table 7).

Comparisons of the June, 0.35-mm screen study with the 0.15-mm screen study indicated much smaller numbers of naiddid oligochaetes were present in June. This could be produced by several factors, including differences between sampling effectiveness of the grab (June) and hand corers (July), escape of small naiddids through the 0.35-mm screen, or rapid population increases of naiddids during the five weeks between the two studies. Large increases have occurred in Naididae abundances between June and July every year since 1972, so it is justifiable to assume that at least most of the increases evident between the two comparisons of finer screens, and part of the increase between the regular July survey and corer samples, were due to reproduction. Naididae have the ability to reproduce asexually by budding fully-formed individuals from the caudal end, which enables them to undergo rapid population increases when conditions are favorable. Differences between grab-sampler and corer estimates of the abundances of Chironomidae were not as large as the differences in estimates for Naididae between the two methods.

Nearly all 46 taxa identified in corer samples were present at the 9-m station, but only 43% of all taxa occurred at the 6-m station (Tables

19 and 20). Chironomidae densities were similar at the two depths, but their proportion of the total decreased from 42 to 23% between 6 and 9 m, as naidids were much more numerous at the deeper location. While several other taxa contributed to higher zoobenthic numbers at 9 m, the most important was immature Tubificidae of the type lacking hair chaetae. Taxa represented by 20 or more individuals (= 1/core) were considered numerically important, and were analyzed further (Table 19).

Relative abundances of species within the families Naididae and Chironomidae differed between 6 and 9 m, also. *Chironomus fluviatilis*-form larvae of the larger size (type B) exhibited the clearest difference (Student's t-test, $p < 0.05$, sample variances not significantly different). If the prerequisite assumption that population variances were equal is set aside (Bomeau 1960), several other taxa have significantly ($p < 0.05$) different abundances: *Stylaria*, *Uncinaxis*, *Vejdovskyella*, *Paracladopelma tylus*, *Chironomus* spp. (instars I and II) and total zoobenthos. Tubificidae data characteristically exhibit strongly contagious spatial distribution, which may be overcome partly by transformation of the data to log ($x + 1$). Variances of transformed tubificid numbers at 6 and 9 were not significantly different, and the t-test showed that the mean for 9-m cores was significantly larger. Mean numbers of *Cladotanytarsus*, *Nais* and Naididae sp. 1 at the two depths were dissimilar, but not significantly different. *Chaetogaster diaphanus* and *Pisidium* spp. were absent from the 6-m station. Taxa with larger numbers at 6 m than at 9 m were *Chironomus fluviatilis*-form (type B), early *Chironomus* instars and *Paracladopelma tylus*.

Several naidids (*Amphichaeta*, *Chaetogaster diastrophus*, Naididae sp. 1) were encountered for the first time in this study. In addition, the turbellarian designated "sp. 1" was found to be abundant in the 0.15-mm screen study, but had not been found previously near the Cook Plant. Tows with regular macroplankton nets (0.35-mm screenings) failed to retrieve this animal on July 23, but 0.15-mm nets captured large numbers relative to other zoobenthic taxa. It is apparently small enough to escape through the coarser nets. The three new Naididae may also have been missed earlier because of their small size.

A striking feature of corer samples was the relatively small size of

TABLE 19. Numerically important zoobenthos in macroinvertebrate taxa collected on 0.15-mm screens from depths of 6 and 9 m near the Cook Plant. Data are means \pm standard errors (N=10) of numbers per core.

Taxon	6 m	9 m
Naididae (total)	41.9 \pm 10.8	75.5 \pm 4.8
<i>Amphichaeta leydigii</i>	6.8 \pm 2.7	14.1 \pm 2.9
<i>Chaetogaster diaphanus</i>	12.2 \pm 6.1	18.3 \pm 2.6
<i>Chaetogaster diastrophus</i>	0	2.9 \pm 2.3
Naididae sp. 1 (of <i>Paranais</i>)	5.0 \pm 3.1	2.5 \pm 1.1
<i>Nais pardalis</i>	9.6 \pm 2.4	4.5 \pm 1.2
<i>Piguetiella michiganensis</i>	5.6 \pm 2.0	7.9 \pm 1.6
<i>Stylaria lacustris</i>	0.3 \pm 0.2	2.8 \pm 1.0
<i>Uncinaiis uncinata</i>	1.7 \pm 0.5	7.6 \pm 0.9
<i>Vejdovskyella intermedia</i>	0.6 \pm 1.0	14.4 \pm 2.8
Tubificidae (immature without hair chaetae)	0.4 \pm 0.3	36.7 \pm 8.1
Chironomidae (total)	37.0 \pm 5.9	38.9 \pm 4.9
<i>Chironomus fluviatilis</i> -grp. (form B)	8.4 \pm 1.6	5.2 \pm 1.0
<i>Chironomus</i> spp. (instars I and II)	13.8 \pm 3.4	4.7 \pm 1.1
<i>Cladotanytarsus</i> sp. 2	5.3 \pm 1.1	15.3 \pm 4.8
<i>Paracladopelma tylus</i>	7.4 \pm 1.2	1.6 \pm 0.9
Sphaeriidae - <i>Pisidium</i> spp.	0	
Turbellaria sp. 1	6.8 \pm 2.4	10.6 \pm 1.2
Total counts	88.4 \pm 16.0	171.3 \pm 10.8

TABLE 20. Numerically unimportant zoobenthos in macroinvertebrate taxa collected in the 0.15-mm screen study at depths of 6 m and 9 m near the Cook Plant.

Taxon	Depth
Acari	
<i>Libertia porosa</i>	6m, 9m
Amphipoda	
<i>Pontoporeia affinis</i>	9m
Gastropoda	
<i>Physa integra</i>	9m
<i>Valvata</i> sp.	9m
Hirudinea	
<i>Helobdella stagnalis</i>	9m
Hydroidea	
<i>Hydra americana</i>	6m, 9m
Insecta-Chironomidae	
<i>Chironomus-anthracinus</i> -gr.	9m
<i>Chironomus-fluviatilis</i> -gr. (A)	9m
<i>Cryptochironomus</i> spp.	6m, 9m
<i>Heterotrissocladius</i> cf. <i>grimshawi</i>	9m
<i>Micropectra</i> sp. 2	9m
<i>Monodiamesa tuberculata</i>	9m
<i>Parachironomus</i> cf. <i>demeijerei</i>	6m, 9m
<i>Paracladopelma</i> spp.	6m, 9m
<i>Polypedilum scalaenum</i>	9m
<i>Potthastia longimanus</i>	6m, 9m
<i>Procladius</i> sp.	9m
<i>Psectrocladius simulans</i>	9m
<i>Tanytarsus</i> sp. 1	9m
Oligochaeta-Naididae	
<i>Chaetogaster limmaei</i>	9m
<i>Nais simplex</i>	6m
<i>Paranais fričii</i>	9m
<i>Paranais littoralis</i>	9m
<i>Pristina foreli</i>	9m
Oligochaeta-Tubificidae immature	
with hair chaetae	9m
<i>Limnodrilus hoffmeisteri</i>	9m
<i>Peloscolex freyi</i>	9m
<i>Potamothrrix vejdoskyi</i>	9m
Pelecypoda-Sphaeriidae	
<i>Sphaerium nitidum</i>	9m
<i>Sphaerium striatinum</i>	9m
Turbellaria	
<i>Gyratrix hermaphroditus</i>	9m
<i>Turbellaria</i> sp. 3	9m

standard errors relative to the means. Total zoobenthos, for example, had a standard-error-to-mean ratio of only 0.06 at the 9-m station. The ratio was somewhat higher, and more typical of zoobenthic data in general (0.18), at 6 m. In general, Naididae species had relatively larger standard errors (ratios greater than 0.25), while Chironomidae species (especially *Chironomus*) had smaller ones (Table 19). Although corer samples were much smaller in surface area than grab samples, they yielded data with comparable or superior characteristics of statistical precision. This may be attributable to more consistent collection (constant penetration depth, lack of a pressure wave) preceding the hand corers or the more consistent retention of macroinvertebrate taxa by the finer screen. Corer samples clearly give better information about population age and size distributions, as evidenced by high retention of first and second instars of several chironomids. However, collection of hand cores is time-consuming and dangerous in windy weather or depths greater than those sampled in this study, and would not be advisable for large-scale surveys.

A methodological implication of the 0.15-mm screen study is that regular survey techniques do not provide an accurate or thorough view of zoobenthos at shallow depths, because so many members of the characteristic taxa are small enough to escape partly or completely through 0.5-mm screens. Moreover, comparisons between Tables 19 and 20 and the conceptually typical species of benthic depth zone 1 (8.1-16 m) shows that the 9-m station was not at all representative of its zone. Although there were numerous differences in species composition at 6 m and 9 m, *Pontoporeia* comprised only 0.4% of the zoobenthos and Sphaeriidae contributed just 2% at 9 m. Considerable differences in zoobenthic composition occur within zone 1 depending on depth.

IMPLICATIONS OF PREOPERATIONAL STUDIES FOR DETECTION OF OPERATIONAL EFFECTS

At this point, between almost five years of preoperational investigations and initial postoperational studies, it is appropriate to pose three critical questions of benthic studies at the Cook Plant. How good are the basic data as a description of the benthic community? What will be the limitations on ability to detect changes in zoobenthos which may occur as

a result of Cook Plant operation? How vulnerable are benthos near the plant to potential impacts of operation? These questions have been addressed to some extent in a previous report (Mozley 1974), but answers can be expanded on the basis of additional data.

Quality of the basic data depends on several factors, including accuracy of numerical estimates, ability to support inferences about important functional characteristics of the community, and the detail with which species composition is known as a function of time and space. The largest set of data consists of regular survey collections with the ponar grab and 0.5-mm screen. These procedures are more or less standard for Great Lakes benthic macroinvertebrate studies, although some investigators have used slightly coarser (U.S. Standard Sieve #30, 0.6 mm) screens and different models of the ponar grab, which have somewhat different sampling characteristics (Mozley and Chapelsky 1973; Mozley 1974). A further, perhaps important difference between Cook Plant procedures and those at other Great Lakes sites is the use of an elutriation device. The greater effectiveness of the triplex version of the ponar grab and the mesh size used on Cook surveys insure that the representativeness of present data is at least equal to those of most Great Lakes benthic studies.

However, these "standard" procedures do not yield accurate estimates of the abundance of many important species, particularly shallow assemblages of chironomids and naidids. Some taxa are retained effectively in all stages (*Pontoporeia*, Sphaeriidae), and others are retained on the 0.5-mm screen in adult stages when they become identifiable to species (Tubificidae), but large percentages of younger stages of Oligochaeta can pass through. The result is that standard methods give an unbalanced representation of zoobenthic species composition, but are sufficiently effective to describe broad outlines of the occurrence of many taxa which are known to be positively or negatively responsive to environmental changes in Great Lakes benthic habitats. In the interest of greater accuracy and more extensive representation of the fauna, it would be desirable to sample sandy bottoms at depths less than 8 or 10 m with coring devices and finer screens.

Another aspect of the quality of benthic data is seasonal coverage. Surveys were not taken as frequently as might have been preferred in

shallower areas. Changes in many species' abundances proved to be large and rapid in summer, and annual maximums may have lasted only a few days or weeks for many species. Moreover, no samples were collected for benthos in the lake in winter months, when *Pontoporeia* and possibly other taxa have reproductive periods. This was due to financial and physical restraints on winter operation of the research ship R/V MYSIS imposed by unpredictable ice development. For all its shortcomings, the data base from the Cook Plant area covers spring, summer and fall periods for many species over a period of four years. These data are the most extensive preoperational information ever collected for a shore-sited power plant on the Great Lakes, and have provided insights into seasonal fluctuations and year-to-year shifts in patterns and composition which might otherwise have been attributed to plant impacts. Changes observed near the Palisades Plant illustrate the interpretative problems which can arise in comparisons which lack those insights (Consumers Power Company 1975).

Spatial coverage is also extensive, including large numbers of stations spread over a relatively broad range of depths and a long stretch of shoreline (Mozley 1974). The least effective representation of spatial distribution was in depth zone 0, where random distribution of stations in major surveys from July 1972 to April 1974 resulted in incomplete and highly variable data. Zone 0 proved to have a steep gradient in zoobenthic abundance as a function of depth within the zone, and to a lesser extent, so did zone 1. Consequently, chance occurrence of randomly distributed stations in the shallower or deeper parts of zone 0 caused greater fluctuations in the data than most month-to-month events such as reproduction or mortality.

It was possible to establish reference areas for comparison with areas near the plant in similar habitats, because of the relatively straight, even shoreline and smooth topographic gradients in southeastern Lake Michigan. A gradient of eutrophication was detected over the 22-km span of the Cook survey area, increasing from north to south. Data from both north and south reference areas will enable distinctions of shifts in the along-shore gradient from plant effects.

The capacity to detect changes in zoobenthos which may occur as a result of operation is set by the precision with which preoperational populations could be estimated. One way to examine precision is to determine

the smallest true change in population densities which can be detected from comparison of preoperational data at the 0.05 significance level. Earlier, this change was found to be approximately 60 to 650% of the means for total counts in various depth intervals (Mozley 1974). In a more elaborate calculation of the least detectable true change, Johnston (1974) estimated that anything less than a 5.48-fold change in the ratio of counts at inner stations to counts at outer stations would not be accepted as significant at the 0.05 level. Limits on the capacity to detect change in the model employed for Cook Plant benthos data (Johnston 1974) are imposed by the variances of population estimates for the various zones and the year-to-year changes in preoperational ratios of counts from inner and outer stations in each zone. The former factor is the larger of the two. Variances of population estimates for zones are based on station means, not on replicate casts at each station. Variances were smaller for certain species than for total counts, allowing detection of much smaller proportional changes in their populations (refer to section entitled "Inner-Outer, Graphical Comparisons" above).

In demonstrations of environmental degradation based on zoobenthos abundances (e.g., Johnson and Matheson 1968), ten-fold increases or local extinction were the criteria for accepting apparent differences as indicative of environmental change. Changes of these magnitudes, if sustained for several years, will be readily detectable when compared with preoperational results at the Cook Plant.

Extensive sets of species-level data have been obtained for several diverse and taxonomically difficult groups of zoobenthos near the Cook Plant. Whether it will prove necessary to call on this data base to detect ecological impacts of the plant remains an open question. There is not yet a good foundation of information or understanding for prediction of benthic responses to large-volume, heated effluents in Great Lakes habitats. Some species have not been identified yet, particularly those in the genera *Lymnaea*, *Ammicola*, and *Chironomus*, Turbellarians, non-dipteran insects, crustaceans and other taxa. Except for *Chironomus* these have been rare in preoperational collections, or were not effectively sampled by survey procedures.

Present estimates of zoobenthic composition at the Cook Plant are

probably about as precise as in any existing benthic study. However, functional understanding and structural information other than species-abundance relationships in benthic communities near the Cook Plant consists solely of inferences derived from regular field surveys. Rates of energy or materials transfers within the community, primary pathways of energy flow, the sources of energy at the lowest trophic level and the degree of trophic interaction between benthos, fish and plankton are still poorly understood. Thus it may well be possible to map the extent of integrated impacts of plant operation on benthic communities, but impossible to determine the mechanism responsible for the observed impacts. A trophodynamic approach to ecosystem analysis would have been a useful, if expensive, addition to preoperational studies.

The third question, that of vulnerability of zoobenthos near the Cook Plant to potential impacts of operation, can be answered on several levels. Potential impacts include scour from discharge currents, mortality, accelerated development or changing competitive abilities resulting from elevated temperatures, increased losses to predators which are attracted by the heat or artificial, solid substrates at the plant, and toxic effects of chlorination residues in discharge water. These issues have been discussed in a general fashion in previous reports and papers (Mozley 1974; Mozley, in press). At some point near the discharge, bottom-living animals will probably be affected by all of these and other unexpected phenomena. It is unclear how large the affected area will be. A minimum estimate would be the distance to which an increase in current speeds near bottom is caused by the jet discharges. The maximum extent could be set by several expected influences (e.g., the sinking plume), or by indirect influences of effluents or structures. Prediction of effects requires many pieces of information about nearshore habitats and organisms in Lake Michigan which are not available, nor easy to discover. Several such pieces are the time-averaged position of the winter temperatures (Hoglund and Spigarelli 1972), the relative importance of predation and competition in determining the structure of benthic communities, and responses of Great Lakes zoobenthos to chronic, sub-lethal concentrations of chlorination residues.

At another level, benthic vulnerability can be formulated as the ability of indigenous species to recolonize areas subjected to lethal treatments. It is ordinarily assumed that the recolonization rate is

sufficiently low for benthos distributions to reflect transient environmental impacts for long periods of time, certainly a matter of months. The shallowest benthic habitats in Lake Michigan, however, appear to be in a continual mode of immigration and emigration. Large populations of every common species near the Cook Plant also exist north or south of the plant, and can serve as epicenters for repopulation of affected areas denuded by transient impacts such as high temperatures or dissolved toxins. Conversely, zoobenthos in these areas may be displaced several times every year by the natural effects of storms. Therefore, no lasting or irreparable impacts of power plant operation are anticipated at depths less than 8 m.

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